The Confederacy of Mainland Mi'kmaq

Fish Spatiotemporal Occurrence and Relative Abundance at the Avon Causeway and Kennetcook River, Nova Scotia

2023-2024

REPORT FOR NOVA SCOTIA DEPARTMENT OF PUBLIC WORKS

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Executive Summary

Monitoring has occurred under various frequency upstream and downstream of the Avon causeway since 2017, with sampling occurring during numerous operational scenarios including freshwater reservoir, brackish reservoir, natural river state and natural river state with some tidal entry. Monitoring on the Kennetcook River, a free-flowing tidal river and control site for the Avon River has been monitored in a similar manner since April 2022.

The monitoring approach has always been focused on collaboration and now utilizes expert knowledge from the Confederacy of Mainland Mi'kmaq, commercial fisher and local expert Darren Porter, Acadia University, CBCL, Innovasea, Oregon RFID, and CHS Labs with insight from both the Province of Nova Scotia and the Department of Fisheries and Oceans (DFO). This approach has proven to increase the availability and quality of data available, reduce data gaps and provide a clearer understanding of the impacts to fish and fish habitat likely caused by the structure and associated gate operations. This approach provides the best available science and should be the default approach for all monitoring endeavors.

In recent years, monitoring using multiple sizes of gillnet as well as eel traps, minnow traps and more recently, a beach seine, has occurred twice per week to produce relative abundance catch data from April to June, once per week from July to October and twice per week from November to when the ice hits in January. Internal tags (Passive integrated transponder – PIT) and external tags (t-bar and dart tags) were also regularly deployed in commonly caught species during each survey. This sampling effort enabled the acquisition of sufficient catch data to perform analysis and comparison of Catch Per Unit Effort (CPUE) as well as sufficient tag deployment and subsequent recapture histories to enable analyses of spatial capture-recapture (SCR) models including survival and population estimates for American eel, Atlantic tomcod and striped bass. Tag recapture data remains insufficient for a similar analysis of gaspereau, and American eel were only detected to have passed through the causeway 97 times since 2019 using tag recapture data suggesting that analysis would benefit from an increase in sampling frequency, especially where twice per week monitoring provides only a snapshot of 14% of the tides.

Fish passage is very much dependant on the operation of the causeway gates. Fish passage cannot occur when gates are closed. Under reservoir conditions where gates are open even for 30 minutes near equalization results in absolute blockage of fish for 91.7% of the time. Suitable conditions including habitat characteristics, low enough downstream water velocities (head pressure) and the occurrence of a regular and sufficient ecological maintenance flow must be provided in order for fish to first be at the structure and secondly to facilitate safe passage. Freshwater reservoir conditions allow the passage of very limited abundances of gaspereau and striped bass (seven gaspereau and one striped bass caught upstream of the causeway before May 21 in 2019) and pass few if any Atlantic tomcod. Operations that produce a brackish reservoir enables the passage of a limited abundance of Atlantic tomcod, gaspereau and striped bass through the structure, while natural river state with intentional saltwater entry passes Atlantic silverside, Atlantic tomcod, flounder, gaspereau, rainbow smelt, striped bass, and other estuarine species. Gaspereau, Atlantic tomcod and American eel were most damaged under reservoir conditions when gates opened near equalization. Gaspereau, Atlantic tomcod and American eel

were least damaged under natural river state, and little damage was observed in other species mostly due to infrequent catches and low abundance.

Several important species are significantly impacted by gate operations including rainbow smelt, Atlantic tomcod and Atlantic salmon. Although historically a large rainbow smelt migration occurred on the Avon, abundances are currently very low. Nearly all rainbow smelt were observed upstream of the causeway under natural river state with intentional saltwater entry. Atlantic tomcod also appear to require water to flow upstream of the causeway in order to pass with passage more efficient under natural river conditions and intentional saltwater entry. Also of consideration is that four inner Bay of Fundy (iBoF) Atlantic salmon were captured in close vicinity to the Avon causeway since 2018 showing the persistence of this species on the Avon River. Two adults caught in 2022 were confirmed to be SARA listed iBoF Atlantic salmon through genetic analysis by DFO.

PIT tagging also provided insight into general movement patterns of especially American eel and Atlantic tomcod, which showed a high degree of connectedness (fish movement) between rivers within the greater Avon Estuary. This suggests that impacts of tidal barriers are not isolated to resident populations but likely have impacts on American eel and Atlantic tomcod throughout the region. Further tagging using acoustic telemetry is proposed after a successful deployment of 180 and 307 kHz receivers downstream of the causeway in January 2024. This trial provided evidence that both the 180 kHz and 307 kHz systems perform well, although there is a clear advantage in using the 180 kHz system as this is the only system where pressure tags are available to provide a depth position, and there are also numerous tagged fish and receivers utilizing the 180 kHz system that have already been deployed. An acoustic tagging program will help enable an understanding of fish behaviour at the structure and address if and when passage is being attempted and the number of passage attempts being made through the structure by representative species.

Water quality was also assessed where a lack of natural tidal flow upstream of the causeway likely contributes to higher temperature ranges. Gate operations also have a large impact on salinities both upstream and downstream of the causeway. Regular and large fluctuations in salinity, especially under reservoir conditions, create unstable conditions and disruptions to the ecosystem both upstream and downstream of the causeway. The estuarine salt wedge was occasionally observed as far as several kilometers downstream of causeway under high runoff events, especially when a reservoir is maintained. This leads to potential harm to the benthic community, including species such as Corophium (amphipod) that is depended on by migratory shorebirds.

Dissolved oxygen (DO) minimums are lowest under reservoir conditions and improve notably under natural river state, especially with increased tidal flow. Lack of downstream flows when gates are closed likely depleted DO levels and causing conditions insufficient for the conservation and protection of fish and fish habitat. Measurements of pH provided further insight confirming that higher water quality stability occurs under natural river state conditions with instability occurring under reservoir conditions. Overall, pH levels consistently remain within CCME estuarine guidelines on the Kennetcook River but fail on the Avon River, especially under reservoir conditions. Also of note is that high *Escherichia coli* (*E. coli* bacteria) levels were observed through testing in 2023, which exceeded Health Canada guidelines on several occasions. An expected point source of this contamination is from a combined sewer outflow in downtown Windsor.

Habitat Suitability Index (HSI) surveys conducted upstream of the causeway and on the Kennetcook River show that poor pool quality is a widespread issue in both watersheds with some sedimentation issues observed primarily in the Avon, and largely associated at sites adjacent to agricultural lands. Such sites present good opportunities for habitat remediation of offsetting projects. However, good cover for fry was identified at most sites along with suitable water temperatures. Good riffle-run substrate was also identified in forested regions largely associated with regions further upstream in both watersheds. pH was assessed as suitable for Atlantic salmon at all sites other than on the West branch Avon (pH 5.38) and Tomcod River (pH 4.23) in the Kennetcook Watershed. Bird surveys were also carried out beginning in fall 2023 and show differences in habitat quality between upstream and downstream of the causeway. Hundreds to upwards of 1000 birds (typically geese and ducks) were often observed on the Kennetcook River and downstream of the Avon causeway in fall 2023 while few to zero were observed upstream of the causeway. This is compared to hundreds of birds observed upstream of the causeway under natural river state in previous years. This drastic reduction in bird abundance and diversity upstream of the causeway strongly suggests that the re-establishment of the reservoir in June 2023 caused a substantial disruption to the habitat and breakdown of the ecosystems ability to support higher trophic levels.

Continued pre-construction monitoring will make available further data needed to assist the ongoing development of more advanced data analysis, which will increase our understanding of fish passage thorough the existing gated structure.

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1.0 Purpose and Historic Context of Study

Monitoring work on the Avon causeway from 2017 to 2019 was funded through the Nova Scotia Department of Transportation and Infrastructure Renewal (now Public Works) and was undertaken in partnership with the Confederacy of Mainland Mi'kmaq (CMM), Darren Porter (commercial fishery), and Acadia University (Dr. Trevor Avery). The goal of this monitoring was to work collaboratively using the best available experts representing multiple knowledge systems to produce a contemporary baseline for species use and fish passage. This baseline has since been and continues to be utilized to inform work being conducted to twin Highway 101 and replace the existing gated structure that currently provides tidal flood mitigation for the Town of Windsor, Village of Falmouth and approximately 2,100 ha of protected agricultural marshland.

The gated structure at the Avon causeway was built from 1968 to 1970 and is currently operated by the Nova Scotia Department of Agriculture (NSDA). This gated structure was previously operated to provide some tidal flow as a means to pass fish (Nova Scotia 2015); however, beginning in the mid-1980s, operation of the structure was modified and ceased to provide adequate multi-species fish passage by eliminating intentional saltwater entry and in later years, concentrated on one commercial species: gaspereau (a species complex consisting of alewife and blueback herring). In the early 2000s, the NDSA worked with the Department of Fisheries and Oceans (DFO) to develop and follow recommendations on gate operations during the spring fish migration to increase compliance with the *Fisheries Act*. These recommendations included:

- From April 15 to May 5, the Gates should be opened whenever the head difference from Lake Pesaquid to the river downstream of the gates is less than 1 foot;
- From May 6 to May 27, during the drawdown of Lake Pesaquid, the Gates should be opened whenever the water level downstream of the causeway is lower than the water level upstream of the causeway; and
- From May 28 to June 30, the Gates should be opened whenever the head difference from Lake Pesaquid to the river downstream of the gates is less than 1 foot.

In 2017 and 2018 (during and shortly after the Environmental Assessment [EA] process) the NSDA voluntarily explored opportunities to improve fish passage by reducing lake levels earlier in the migration season, extending these operations later in the season and aligning maintenance activities of the structure. However, in 2019 the NSDA only provided natural river conditions on 12 tides, which all occurred in May. Gate operations in 2020 followed the typical 2000s protocols and a Ministerial Order was issued on May 14, 2020 that required the NSDA to not impound water upstream of the causeway from April 1 to June 15, ensure both gates are fully opened during the falling tides and not closed until the incoming tide is equalized with upstream levels, and to develop a fish passage plan for the remainder of the year. While flows at the Avon 1 and 2 hydropower facility (operated by Nova Scotia Power) were reduced for a prolonged period near the end of May 2020, fish were stranded in developing side channels resulting in a fish kill upstream of the Avon causeway on May 28, 2020. Gate operations were quickly adjusted thereafter resulting in the establishment of a saltwater reservoir, which was eventually converted back to fresh water in September 2020.

Pre-construction monitoring continued in 2020 through the support of Oceans North and again in 2021 through support from both Oceans North and the Aboriginal Aquatic Resource and Oceans

Management Fund (AAROM). This ongoing fish passage and environmental monitoring led to the implementation of DFO's second Ministerial Order, issued in March 2021, which outlined operational requirements of the Avon River gated structure. This order required gates to be fully opened on the falling tide, did not permit impoundment of water upstream of the structure and required gates to be fully open during the incoming tide to allow a minimum of 10 minutes of saltwater intrusion.

Additional pre-construction monitoring was requested by the Mi'kmaq through consultation, and the Nova Scotia Department of Public Works agreed to support ongoing monitoring on the Avon and Kennetcook Rivers, as outlined within CBCL Report 171046.01, contained within the document "Update to Application for Highway 101 – Avon River Aboiteau and Causeway Upgrading Design Fisheries Act Authorization Application Phase 2 Aboiteau and Bridge Construction", which was submitted to DFO on August 24, 2021. Public Works continues to collaborate with DFO and the Mi'kmaq through consultation on all fish passage and monitoring requirements. Since spring 2022, the CMM has administered funding received from the province to project partners who collectively carry out a pre- and post-construction monitoring plan that has been developed in collaboration with CBCL. This monitoring plan follows a before-after control-impact (BACI) design that includes monitoring of fish passage upstream and downstream of the Avon causeway and monitoring of fish relative abundance on the Kennetcook River. Although the physical features and usage by fishes vary by river, the Kennetcook River does not have a tidal barrier and has the most comparable watershed size of the rivers located in close proximity to the Avon River (the Avon River watershed is $472km^2$ while the Kennetcook River has a watershed size of $503km^2$). This makes it an optimal control site to compare against and determine naturally occurring interannual variability in fish assemblages and relative abundances. Monitoring in 2022-2023 expanded the pre-construction baseline assessment of fish spatiotemporal occurrence and relative abundance at the Avon causeway and initiated a similar baseline on the barrier-free control site, the Kennetcook River.

On June 1, 2023 the Minister of Municipal Affairs and Housing, John Lohr, declared a state of emergency for the "area around and including Pisiquid Lake, Windsor, Hants County of Nova Scotia" citing concerns on the availability of water resources for fire suppression purposes. A directive was also given to the "owners and operators of the sleway connected to Pisiquid Lake, and any associated infrastructure" directing them to manipulate the sleway with the "goal of maximizing the water supply resource available for the wildfire suppression efforts". On June 10, 2023 the Ministerial Order issued by DFO in 2021 was not renewed. This state of emergency and associated directive has been renewed every two weeks to maintain a largely freshwater reservoir. One gate was typically operated to open for approximately 10 minutes near equalization, four time per day. On October 5, 2023, the last renewal before the official end of the wildfire season (October 15), the goal of the directive was adjusted from "maximizing the water supply resource available for the wildfire suppression efforts" to "maximizing the water supply resource available for fire suppression".

Monitoring in 2023-2024 further developed the program on the Avon and Kennetcook Rivers, to include beach seining and an acoustic receiver test deployment downstream of the causeway. This monitoring report addresses the three overlying objectives presented in this monitoring plan, which include assessment of fish passage effectiveness, fish passage efficiency and changes in fish habitat.

2.0 Objectives

This monitoring program serves to provide the best available science with respect to which fishes are likely to use the system and what gate operations optimize fish passage through the Avon causeway. Our operational monitoring framework is continually adapting and strives to integrate multiple knowledge systems to produce a wiser and more thorough science. The program follows an integrated planning and monitoring approach, including through the interpretation of results with the goal of improved analyses, understanding and agreement between all parties involved.

Table 1 Monitoring objectives, activities undertaken and status in 2023-2024.

Objective	Key Response Variables	Monitoring Activities Undertaken	Status in 2023-2024
Objective 1 – Integrating Multiple Knowledge Systems	-Maintain the collaboration of multiple knowledge systems including integrated planning, monitoring, analysis and interpretation of results.	The monitoring team includes in-depth collaboration between the Confederacy of Mainland Mi'kmaq, Commercial fisher Darren Porter, Acadia University and CBCL, with notable contributions from Innovasea, Oregon RFID, CHS Labs and the NS Department of Agriculture. The monitoring program is also coordinated between the Province of Nova Scotia, the Department of Fisheries and Oceans, and the Kwilmu'kw Maw-klusuaqn Negotiation Office.	Ongoing
Objective 2 – Assess Effectiveness of Fish Passage	-Determine fish species presence and relative abundance (e.g., catch per unit effort) upstream and downstream of the Avon causeway and on the Kennetcook River.	Ongoing boat based CPUE (upstream and downstream of the Avon causeway, and on the Kennetcook River) using beach seine, gillnets, eel and minnow traps.	Ongoing
	-Assess success of entry, passage through, and exit up and down the fishways throughout the tidal cycle.	Ongoing capture-mark-recapture program through CPUE and trial deployment of PIT tag receivers in Avon and Kennetcook Rivers	Trial and Error[1]

Objective	Key Response Variables	Monitoring Activities Undertaken	Status in 2023-2024
	-Assess length of time it takes fish to enter and move up or down the fishway.	Trial deployment of acoustic tag receivers downstream of Avon causeway	
	-Assess fish survival rates from all sources through a capture-mark-recapture study.	Ongoing capture-mark-recapture program through CPUE and trial deployment of PIT tag receivers in Avon and Kennetcook Rivers	
Objective 3– Assess Efficiency of Fish Passage	-Evaluate the magnitude and scope of any potential damage occurring to fish that pass through the causeway and on the Kennetcook river, including a high-level assessment of cumulative effects.	Ongoing boat based CPUE (upstream and downstream of the Avon causeway, and on the Kennetcook River) using beach seine, gillnets, eel and minnow traps. All fish are visually assessed for damage.	Ongoing
	-Assess differences in mean CPUE between upstream and downstream of the causeway (a significant difference would suggest inefficient passage).	Ongoing boat based CPUE (upstream and downstream of the Avon causeway, and on the Kennetcook River) using beach seine, gillnets, eel and minnow traps.	
	-Assess differences in run time (delays in migration) between the two rivers (an extended migration at the causeway compared to the Kennetcook river would suggest inefficient passage).	Ongoing boat based CPUE (upstream and downstream of the Avon causeway, and on the Kennetcook River) using beach seine, gillnets, eel and minnow traps.	
	-Assess behaviour of fishes interacting with structure. Is passage being attempted? -Assess number of passage attempts made through the structure by representative species (American eel, Atlantic	Trial deployment of acoustic tag receivers downstream of Avon causeway for ability to position fish in at least 2D and potentially 3D.	Trial and Error[1]

Objective	Key Response Variables	Monitoring Activities Undertaken	Status in 2023-2024
	salmon, Atlantic tomcod and gaspereau).		
Objective 4 – Evaluate Changes in Fish Habitat	-Assess changes in and suitability of water quality (e.g., surface water salinity, temperature, dissolved oxygen levels, turbidity, and concentration of total suspended sediments).	Handheld measurements of water quality using a YSI as well as deployment of HOBO loggers on the Avon and Kennetcook Rivers.	Ongoing
	-Assess changes in and suitability of fish habitat (e.g., spatial extents of saltwater and suspended sediment intrusion, changes in assessed habitat suitability index)	Habitat Suitability Index assessments, bird surveys, water quality measurements.	

[1] Trial and Error indicates a period intended to identify specific methods and locations suitable for implementation in the Avon and Kennetcook Rivers.

3.0 Objective 1 - Integrating Multiple Knowledge Systems

3.1 Methods

Our monitoring approach strives to achieve and maintain a strong working relationship between the CMM, commercial fishery and academics to combine Mi'kmaq knowledge, local knowledge and academic knowledge. Combining the strengths of each knowledge system allows us to collect data in a manner that is repeatable and with increased credibility leading to outcomes and interpretations that are more reflective of the ecosystem. This collective knowledge is essential to provide a clearer assessment and understanding of a particular ecosystem. Collaboration and knowledge sharing are fundamental to the success of this project and result in all partners gaining greater confidence in the validity and credibility of the findings, which reduces perceived and realized conflicts in the interpretation of results. This collaborative framework is always evolving and as new insights are gained from different points of view, analyses and elements are added to the monitoring program to address these questions or concerns as they are brought forward.

3.2 Benefits of Combining Knowledge Systems

As a local fisher, Darren Porter and his crew represent the local knowledge system (through the lens of the commercial fishery) and collectively have decades of local fishing expertise with much of that time gained from working within these study rivers. Darren's local knowledge, gained from working in this extreme region, has allowed him to design a well-adapted vessel for carrying out monitoring activities and has prepared him to be able to conduct surveys in a reliable, repeatable, efficient and safe manner.

Deep local knowledge of how various wind strengths and directions impacts sea state at different sites is used to adjust weekly monitoring schedules to further maximize safety and minimize data gaps. Collaborations with many partners and Darren's extensive fishing expertise provides an enhanced option to quickly train new staff to enable fluid staffing (a flexible roster of people gathered through each partner organization that can staff monitoring shifts), which minimizes lost shifts and data gaps (especially during academic exam season and through holiday seasons such as Christmas), but also increases efficiency to maximize opportunities for additional data collection such as the ability to include a beach seine survey on most sampling days. Studies with a lower survey frequency quickly become data deficient, which leads to inadequate assessments. For example, surveying less frequently yields a lower probability of capturing and documenting rare species with lower abundances. An insufficient sampling frequency could therefore conclude certain species such as iBoF Atlantic salmon are not present, when in reality, they are present, although in low abundance. Working with commercial fishing license holders also reduces data gaps by providing a stopgap measure in the event of a delay in the issuance of a scientific permit. For example, Section 52 permits from DFO are only issued from January 1 to December 31 of a given year. As the monitoring season spans from April to end of January, a renewal is required mid-season and within the Christmas holiday shutdown. Renewals require submission of a report outlining catches made under the specific permit and so it is common for a lapse in permitting to occur in early January. Without the ability to utilize Darren's commercial license to deploy traps during that time, there would be a notable gap in our understanding of the passage conditions provided during the Atlantic tomcod migration period.

Data consistency and thus quality is also intimately related to the consistent use and quality of bait. Working with local fishers and their commercial licenses provides an excellent opportunity to source a consistent and cost-effective supply of quality bait. This is an important consideration given that if the type of bait is not suitable, changes frequently or is of poor quality, the numbers of fish caught become related to the bait and not the environment. The quality of data has also been improved by mutually implementing a policy where data is electronically entered and stored as soon as possible after collection. An individual is better able to maintain focus if data entry can be limited to one or two hours each day, compared to entering a week worth of data over many consecutive hours. This approach results in a much smaller margin for error and a less severe consequence of misplacing a data logbook. Sampling details are also more easily recalled shortly after field work is done and so any entry errors may be more easily identified and corrected if data is entered into excel after each survey.

A successful fisher knows they need to set nets parallel with the current to ensure nets maintain the intended mesh shape. For example, nets hung on the three-quarters (four squares of mesh picked up for every 6" of buoy line) make a narrower mesh shape to catch fish like gaspereau and shad, while nets hung on the one-half (three squares of mesh picked up for every 6" of buoy line) creates a wider shape for fish that are more rounded such as mackerel. If nets were set perpendicular to the current in a high flow environment the net would bow out and the mesh would be manipulated into a square mesh shape, unlike the shape of a fish, meaning catchability is greatly reduced. Utilizing local knowledge holders and expert fishers that understand the specifics of mesh construction, including which mesh size and set configuration is best suited for each target species, and how to deploy each net to catch each target species, will also greatly improve the consistency and quality of data collection.

Fishers are on the water nearly every day and/or tide and so they have far greater first-hand experience than someone who may sample even two tides a week. As such, local fishers will have a more intimate understanding of ecosystem dynamics, species behaviour, changes over time and how different operations of various infrastructure may impact the overall system. This knowledge is critical in guiding data analysis and interpretation and can even fill data voids such as identifying occurrences of large fish kills based on observations such as unusually large abundances of gulls.

The sharing of knowledge is not unidirectional and local/Mi'knaw knowledge holders also benefit from working alongside academic institutions. Academic systems have become the standard platform for communicating science to the broader scientific community, the courts, our governments, NGO's and others. By working alongside academics, local and Mi'kmaw knowledge holders can learn to effectively communicate their complex understanding of an ecosystem in ways that academics can grasp. These partnerships provide a means of bridging communication barriers and allowing the broader scientific community to further understand other knowledge systems. For example, undergraduate and master's students (primarily co-op students from Acadia University) form an important component of the regular monitoring crew and help carryout day to day monitoring activities. Their direct participation in monitoring work builds their understanding of fishing methods and best practices as well as the context of the data that is collected, which they often use to complete their own thesis and manuscripts. This collectively builds capacity in these research areas and enables students to graduate with a better understanding of the connectedness of these ecosystems and with more confidence in their ability to carry out fish monitoring studies. Over time, this translates into more studies that better reflect ecosystems, meaning the collective understanding of those ecosystems is improving to help ensure their survival for the next seven generations.

The data analysis team within this project is primarily comprised of Dr. Trevor Avery and several of his students, which integrate another aspect of the academic lens into this project. This group provides critical data and statistical analysis to support the report development phase of the project. Much of the regulatory requirements can be fulfilled by working with the academic knowledge system and their expertise in data analysis. Collaboration with other companies and consultants also integrates the best available knowledge on specific topics into the project. For example, Acadia University has formed a strong working relationship with Oregon RFID and CHS Labs to develop and install PIT tag arrays. This working relationship is not just benefiting this monitoring work but is actively providing the opportunity to strengthen the available technology for the broader scientific community. Innovasea is a company that is heavily relied on for their expertise in acoustic telemetry and generously loaned gear for the acoustic trial that was carried out in January 2024. CBCL Limited is also a partner on this project and as the designers of proposed new infrastructure on the Avon River, they liaison with DFO and the Province to align monitoring and reporting with the regulatory requirements. Similarly, data collected through this project informs CBCL of design considerations for ensuring creation of suitable habitat and maximizing fish passage through the proposed new structure.

The CMM and Kwilmu'kw Maw-Klusuaqn Negotiations Office (KMKNO) represent the Mi'kmaq through the Indigenous lens. Mi'kmaw crew members have been able to share their cultural perspectives, such as Netukulimk (take only what is needed and waste nothing), which are then able to be incorporated into the framework of the project. For example, the project team harvests only as many individuals as is needed for bait and laboratory analysis, and we take every effort to ensure as much information as possible is collected from these individuals and any of the very few fish that are incidentally killed through the monitoring work. Mi'kmaw crew members have also been able to build their scientific and working capacity by receiving training and participating in monitoring surveys. These individuals have then taken those learned experiences back to their communities to increase awareness and interest in carrying out monitoring projects. Data and information collected through monitoring surveys feeds directly into the Consultation process to provide Mi'kmaw decision makers with an ability to make informed decisions, and because the CMM maintains a consistent, active and equal role within the data collection activities, Mi'kmaw decision makers have an added layer of trust in the information they receive. Regular monitoring surveys provide real time information to CMM and its partners, who then maintain regular communication with KMKNO to ensure any concerns that arise from either party are addressed early, and with effective and efficient actions. Long-term and consistent collection of information on an ecosystem provides an unmatched ability to assess changes in population abundances, inform fisheries management within all levels of government and carry out more effective and efficient adaptive management responses.

Meaningful communication between all systems of knowledge can often be used to clarify or verify knowledge, which avoids the dismissal or undervaluing of each other's knowledge and progresses our collective understanding of a particular topic. The more knowledge systems interact, the more each are understood by the other, which creates respect for one another. This respect for other knowledge systems provides each with a voice, reduces conflict, and allows positive changes to be made, which is arguably the most important social factor stemming from these partnerships.

However, producing science that integrates multiple knowledge systems is not easy and there is always room for improvements. It is imperative to not dismiss a knowledge system simply because the time was not taken to understand it. The collective monitoring process must include all participating knowledge systems from the beginning, with multiple discussions held to fine tune the monitoring plan, analysis and interpretation of results, as well as a shared writing experience; even if that process is messy or inconvenient. When scientific research is conducted using this integrated approach, there is an inherent opportunity to educate each other and expand collective and individual knowledge. Doing so bridges gaps from knowledge systems, builds lasting relationships, to reduces historical conflict. Elder Albert Marshall suggested that at some point we need to stop just studying and instead take action on what we already know. Two-eyed seeing embodies this statement given that Indigenous and local knowledge holders have kept the project focused on the need to ensure a sustainable fish population for future generations, and so collectively the team strives to ensure data is reflective of the ecosystem and interpreted correctly in order to ensure that the best available science is present to enable evidence-based decisions to be made.

4.0 Objective 2 - Assess Effectiveness of Fish Passage

4.1 Methods

4.1.1 Fish Monitoring Surveys

4.1.1.1 Survey Frequency

Fishing surveys are typically possible in this macro-tidal environment from April to January, inclusive. Sampling in February and March is not carried out due to the presence of large ice blocks in the system that render deployment of gear and/or access from boat ramps extremely challenging. In recent years, surveys have been completed throughout April to January, but temporal gaps in monitoring did occur in 2017 – 2022, primarily due to funding limitations and delays in extending boat ramp infrastructure on several occasions after reservoir levels were dropped (Table 2). The frequency of surveys in recent years has been reflective of known fish migration windows. Sites were typically sampled twice per week in April to June, once per week in July to October and twice per week in November to January. Monitoring surveys have also occurred under several general operational scenarios including a largely freshwater reservoir, brackish reservoir and essentially natural river state. A freshwater reservoir was present from June through April in 2017 and 2018, nearly all of 2019, September 2020 to March 2021 and June 2023 to present. A brackish reservoir existed from June to September 2020 and at times in 2023, and natural river state occurred in late April through early June in 2017 and 2018, for a short time in late May 2019, late April to late May 2020 and from March 2021 to end of May 2023. However, there are nuances in gate operations and conditions within the general categories described. For example more saltwater entry occurred in 2021-2022 compared to 2022-2023, and there were occasions where saltwater entry occurred upstream under freshwater reservoir operating conditions.

Table 2 Survey trips conducted per month by site and year

	April	May	June	July	August	September	October	November	December	January
2017-2018	Reservoir was dropped in late April and freshwater reservoir returned in early June for remainder of year. No intentional saltwater entry.									
Upstream of Avon Causeway	8	4	8	5	6	4	5	2	-	-
Downstream of Avon Causeway	7	10	4	8	7	7	7	1	-	-
Kennetcook River	-	-	-	-	-	-	-	-	-	-
2018-2019	Reservoir was dropped in late April and freshwater reservoir returned in early June for remainder of year. No intentional saltwater entry.									

Upstream of Avon Causeway	6	2	5	13	5	4	4	1	-	-
Downstream of Avon Causeway	6	8	8	7	4	4	4	1	-	-
Kennetcook River	-	-	-	-	-	-	-	-	-	-
2019-2020	Reservoir largely maintained until dropped between late May and early June. Freshwater reservoir maintained for remainder of year.									
Upstream of Avon Causeway	3	8	8	10	6	6	9	5	4	5
Downstream of Avon Causeway	-	2	4	10	6	5	9	4	4	3
Kennetcook River	-	-	-	-	-	-	-	-	-	-
2020-2021	Reservoir dropped in late April until brackish reservoir created in late May. Reverted to freshwater reservoir in September 2020.									
Upstream of Avon Causeway	8	9	9	2	1	2	-	-	2	-
Downstream of Avon Causeway	10	8	10	-	-	-	-	-	-	-
Kennetcook River	-	-	-	-	-	-	-	-	-	-
2021-2022	Ministerial order issued in March, natural river state and min 10 minute saltwater entry occurred for remainder of year.									
Upstream of Avon Causeway	4	2	2	-	3	1	-	5	8	3
Downstream of Avon Causeway	4	4	5	4	4	3	-	5	6	2
Kennetcook River	-	-	-	-	-	-	-	-	-	-
2022-2023	Ministerial order - natural river state and min 10 minute saltwater entry occurred for the entire year.									
Upstream of Avon Causeway	7	4	7	5	3	6	9	7	8	7
Downstream of Avon Causeway	6	6	6	6	5	4	8	9	7	6

Kennetcook River	6	6	6	6	4	5	4	5	5	6
2023-2024	Ministerial order - natural river state and min 10 minute saltwater entry until June 1, then freshwater reservoir with occasional saltwater entry.									
Upstream of Avon Causeway	7	10	8	5	4	4	4	9	8	6
Downstream of Avon Causeway	9	9	8	6	5	4	4	9	8	7
Kennetcook River	8	9	8	5	4	4	4	9	8	6

4.1.1.2 Fishing Gear Deployment Technique

Monitoring activities and gear selection has varied since monitoring began in 2017 but monitoring has consistently utilized boat-based deployment of gillnets and eel traps (Table 3). Minnow traps were consistently utilized in the program starting in 2020 and a beach seine was added in 2023. The use of various gear types, including several gillnet mesh size and material types enable the capture of different sizes and species of fish, enabling a greater ability to document the actual fish assemblages that are using the system. On each survey, captured fish were identified, counted and measured, and where possible and necessary, sexed before being returned to the water.

The gear deployment technique was refined from 2017 to 2019 during which it was determined that gear set for a couple hours caught a similar abundance of individuals compared to gear set overnight, for example. Therefore, setting gear for a couple hours or less provides a higher catch efficiency compared to overnight sets. A shorter soak time is also a more manageable and repeatable method and helps to standardize the catch per unit effort (CPUE; a relative abundance index), calculated the number of individuals caught per unit soak time (fishing period) while considering the amount of gear that was set. In 2019 onward, traps were typically set for fewer than two hours and nets were set for 30 to 90 minutes depending on the water temperature, and more recently, for 30 minute sets to establish an easily repeatable and more standardized fishing effort.

Gillnets, traps and the beach seine only capture a fraction of the fish in the watershed and thus standardized sampling through CPUE is used to compare to other sites where the same gear and methods are used. Impacts of a barrier can then be assessed by comparing CPUE upstream versus downstream of the barrier. Conditions within our scientific permits issued by the DFO typically provided guidance on set periods and were designated based on the protocols Darren Porter had implemented using his expert knowledge of how to avoid mortality or reduce mortality risk. Fish sampling was non-lethal (other than to retain gaspereau under Darren Porter's commercial license for bait during the April to end of June commercial season, or a select number of Atlantic tomcod for various analysis purposes). Once fish were sampled (e.g. measured, tagged, documented, etc.), they were quickly returned to the water.

Visual surveys were also conducted at various sites within the Avon (Figure 1) and Kennetcook (Figure 2) watersheds during known spawning migration windows for American shad, Atlantic tomcod, gaspereau and rainbow smelt. Plotted features are colour coded according to the legends provided in the figures. These surveys were conducted by checking bridges or walking in the river or along the bank in areas where the bottom was clearly visible to assess the presence/absence of spawning activity.

Table 3 Specifications for fishing gear used in monitoring surveys.

Gear Type	Material	Length	Depth	Usage	Target Species
5.5" Leaded Gillnet	Monofilament	100'	10'	Periodically in 2022	adult striped bass, adult sturgeon
3" Leaded Gillnet * nylon snags fish more easy. Salmon roll up in nylon more effectively then monofilament.	Nylon	185'	10.5'	2017-2024	adult American shad, adult Atlantic menhaden, adult Atlantic salmon, adult gaspereau, adult striped bass, adult sturgeon
2.875" Leaded Gillnet	Monofilament	54'	15'	2017-2024	adult American shad, adult Atlantic menhaden, adult Atlantic salmon, adult gaspereau, adult striped bass, adult sturgeon
2.75" Leaded Gillnet	Monofilament	55'	15'	2017-2024	adult American shad, adult Atlantic menhaden, adult Atlantic salmon, adult gaspereau, adult striped bass, adult sturgeon
1.25" Leaded Gillnet	Monofilament	100'	5'	April 1, 2020 - July 3, 2020	juvenile American shad, Atlantic salmon smolt, adult Atlantic tomcod, juvenile

Gear Type	Material	Length	Depth	Usage	Target Species
					gaspereau, adult rainbow smelt
1.25" Leaded Gillnet	Monofilament	114.5'	4.5'	2021 - 2024	juvenile American shad, Atlantic salmon smolt, adult Atlantic tomcod, juvenile gaspereau, adult rainbow smelt
1.25" Leaded Gillnet	Monofilament	87'	4'	Periodically in 2022	juvenile American shad, Atlantic salmon smolt, adult Atlantic tomcod, juvenile gaspereau, adult rainbow smelt
1.25" Leaded Gillnet *lead line overpowered buoy capacity, net soaked low in water column vs at surface.	Nylon	88'	3'	2021-2023	juvenile American shad, Atlantic salmon smolt, adult Atlantic tomcod, juvenile gaspereau, adult rainbow smelt
Beach Seine with 1/8" x 1/8" mesh pocket	Nylon	30'	4'	April 1, 2023 - January 22, 2024	American eel, American shad, Atlantic tomcod, flounder, gaspereau, mummichog, rainbow smelt, stickleback, striped bass. Particularly effective for

Gear Type	Material	Length	Depth	Usage	Target Species
					catching smaller bodied and juvenile fish.
Eel trap (3"x 3" square opening)	Black coated 1"x 0.5" metal mesh	2'	1'	2017-2024	yellow/silver American eel, adult Atlantic tomcod, adult green crab, adult rock crab
Minnow trap (1" diameter opening on each end)	Black coated 0.25"x 0.5" metal mesh	16"	9"	Limited deployment downstream of causeway in 2017. Deployed consistently from April 1, 2020- November 5, 2023	yellow American eel, adult Atlantic tomcod, mummichog
Crawfish trap (2" diameter opening on each end)	Black coated 0.25"x 0.5" metal mesh	16"	9"	November 6, 2023 - January 22, 2024	yellow American eel, adult Atlantic tomcod, mummichog

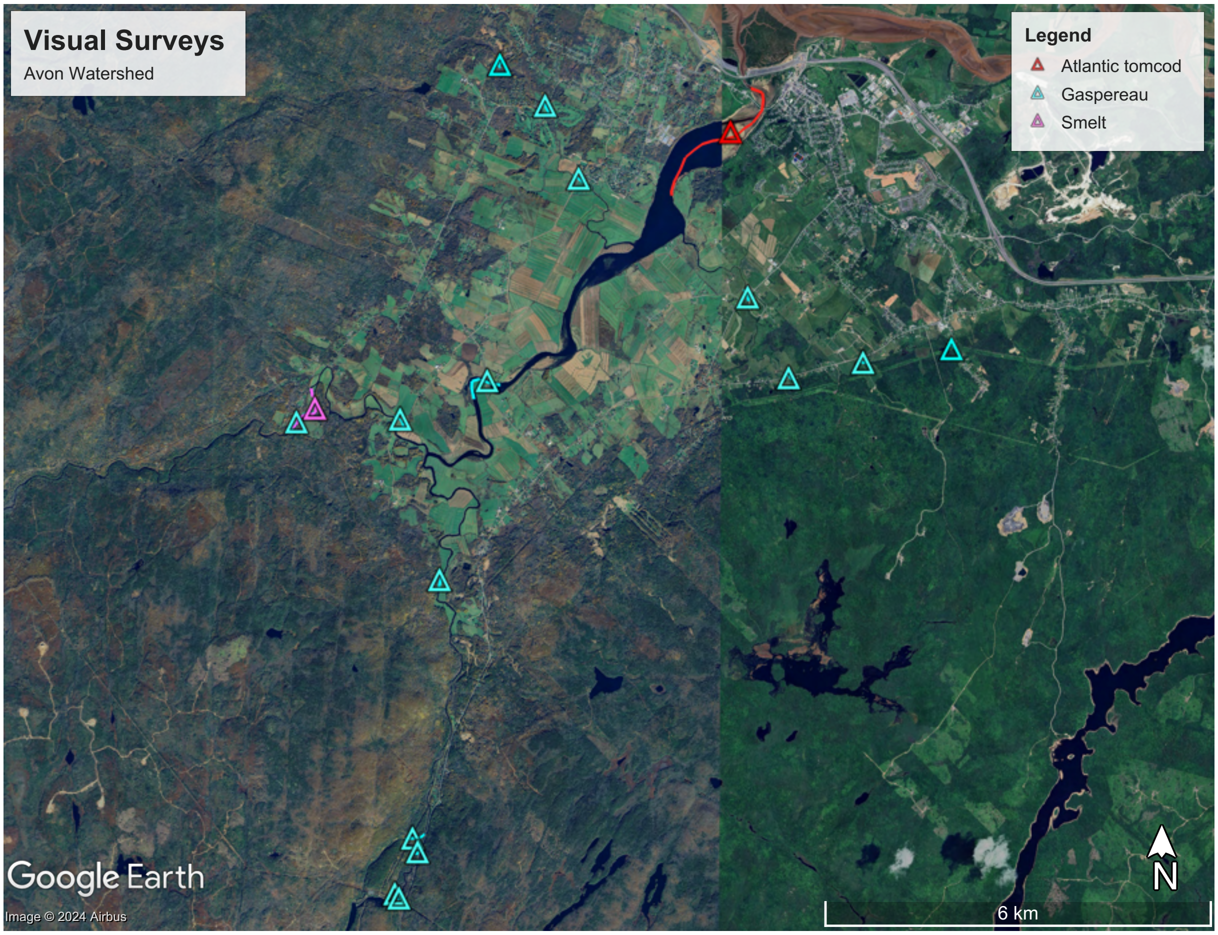

Figure 1 Map of visual surveys conducted on the Avon River.

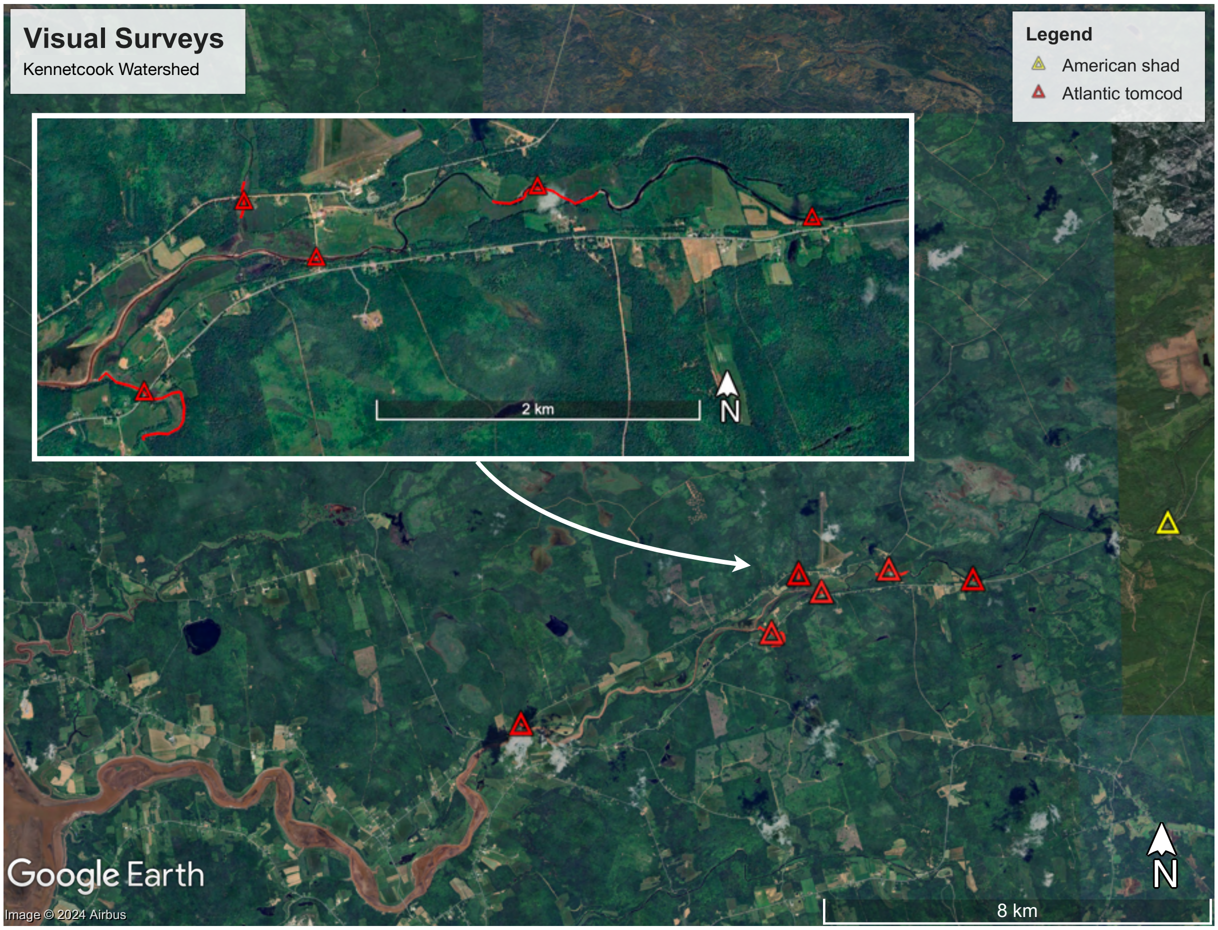

Figure 2 Map of visual surveys conducted on the Kennetcook River.

4.1.1.3 Fishing Gear Deployment Locations

Specific sites for traps were identified using expert knowledge of fish behavior, habitat, river characteristics (e.g. bathymetry), and currents and included areas containing structure and low current to maximize CPUE, as well as in more general areas, to incorporate haphazard sampling. Haphazard sampling is not random sampling because random sites may be impossible to fish; thus, haphazard is the best that can be accomplished given the conditions of the watersheds. Exact sites vary slightly from survey to survey due to difference in flow patterns, shifting habitats, and other factors, although the general site areas remained the same to ensure repeatability in localized area sampling. Gillnets were typically positioned parallel with the wind and currents, which are typically parallel with the river bank.

4.1.1.3.1 Upstream of the Avon Causeway

Sampling upstream of the Avon causeway commenced near or just after the posted high tide time for Hantsport (station 00282) as the gates were closed during that time, which elevated water levels and increased the ability to deploy the boat and fishing gear in a safe and repeatable manner. Extensive spatial monitoring in 2017 and 2018 identified the area near the causeway and trunk 1 bridge as the best place to catch anadromous fish in a consistent and repeatable manner, and to effectively assess fish passage through the causeway. Sampling at sites several kilometers upstream of the causeway may not necessarily portray an accurate representation of fish passage through the structure, especially for species such as Atlantic tomcod, rainbow smelt and others that are unlikely to travel much further than head of tide. Further, water levels vary under different gate operations and for example, operations that enable natural river state render upstream areas inaccessible for fish sampling by boat. As such, spatial sampling upstream of the causeway from 2019 and onward focused on the area from the causeway to just upstream of the Trunk 1 bridge and was spatially similar each year (Figure 3). However, opportunistic sampling with eel traps and smelt nets (1.25" mesh) periodically occurred further upstream, particularly during the Atlantic tomcod and smelt migrations when there was uncertainty over where and if these species may attempt spawning. Gillnets (mesh size 3", 2.875", 2.75" and 1.25") were connected and set in one long stretch until 2020. Thereafter smelt nets were set separately, typically in shallower water and along a bank.

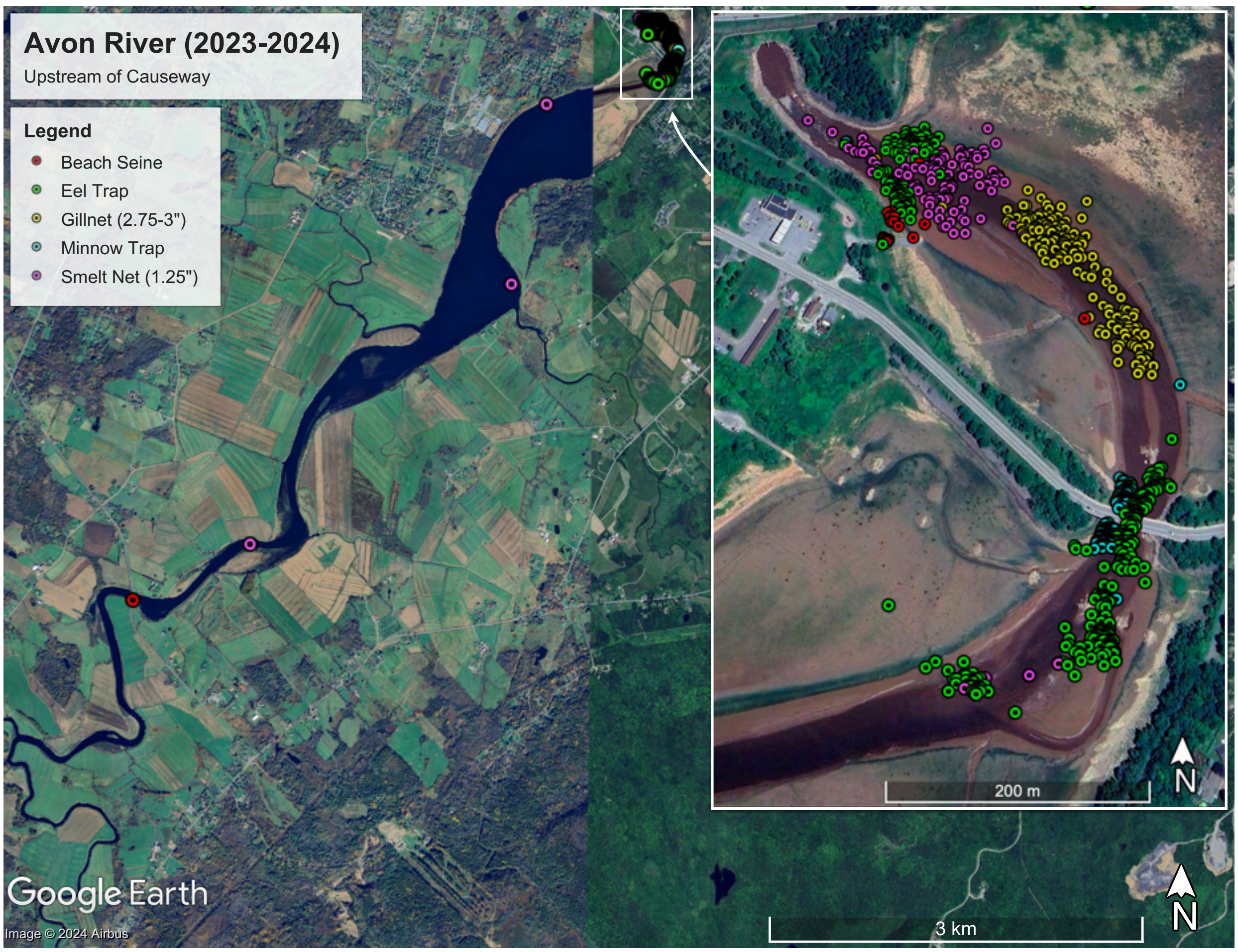

Figure 3 Fishing gear deployment upstream of Avon causeway in 2023-2024.

4.1.1.3.2 Downstream of the Avon Causeway

The majority of fish enter estuaries with the incoming tide, particularly near mid tide (Becker et al, 2016). As such, monitoring surveys downstream of the causeway occurred during the incoming tide when water levels became suitable for launching the boat and deploying gear. Gear deployment typically commenced 2.5 hours prior to the posted high tide time for Hantsport (station 00282). Eel traps were set closer to the causeway in 2017, but from 2018 onward, eel traps were spread further along the main channel from the causeway to the farthest extend of the marsh in attempt to fish similar sized areas upstream and downstream of the causeway (Figure

4). Gillnets (mesh size 3”, 2.875”, 2.75” and 1.25”) were connected and set in one long stretch near the causeway until 2020, after which smelt nets (1.25”) were set separately in shallow water along the east marsh bank.

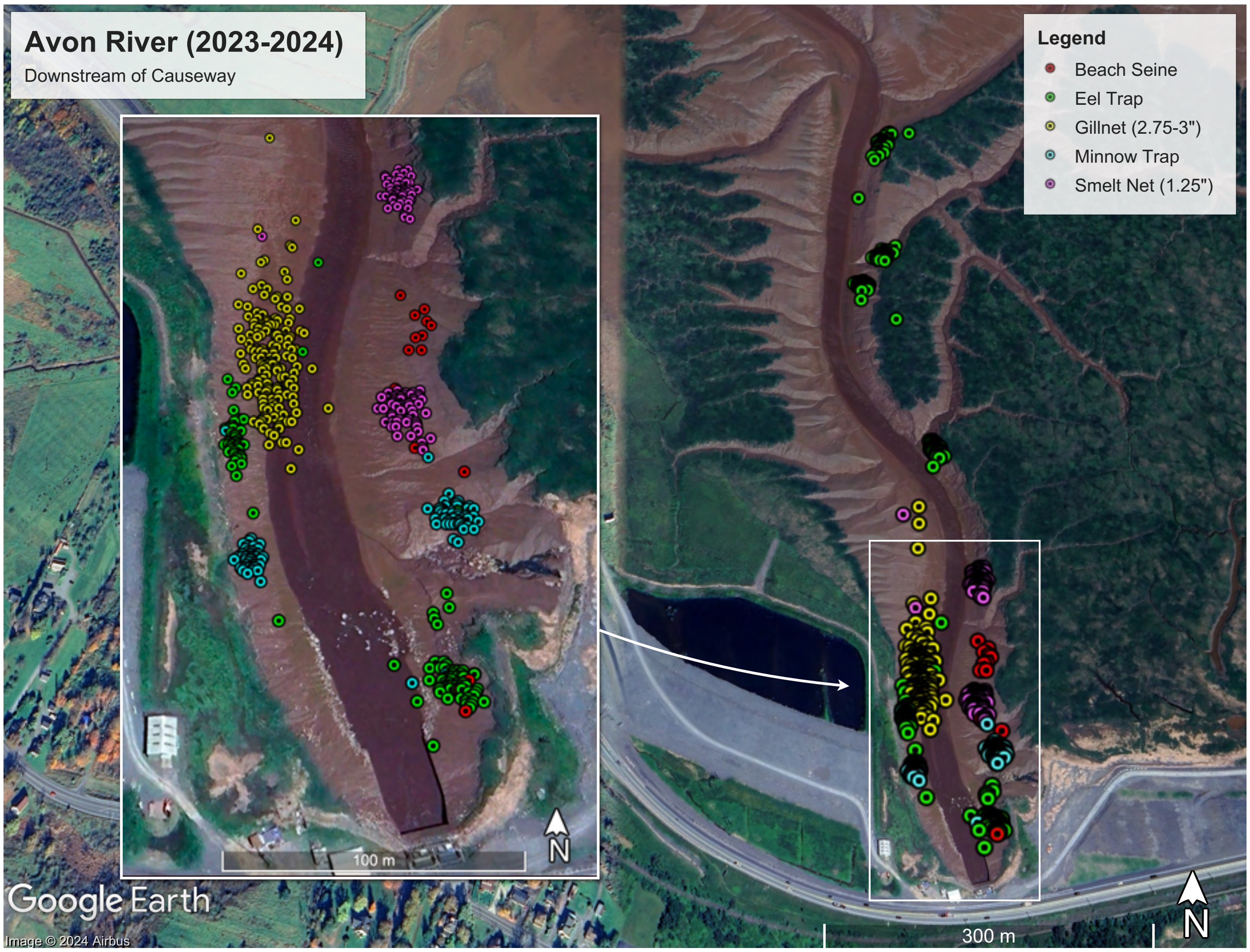

Figure 4 Fishing gear deployment downstream of Avon causeway in 2023-2024.

4.1.1.3.3 Kennetcook River

The Kennetcook River is a barrier-free tidal river and serves as a control site to compare with the tidal barrier site on the Avon River. Monitoring surveys on the Kennetcook River began in 2022 and also occurred during the incoming tide when water levels became suitable for launching the boat and deploying gear. As a non-barrier tidal river, water flows unimpeded upstream during the incoming tide and currents become quite powerful compared to currents at barrier sites, making it difficult to keep gear in one place during certain times in the tide. To mitigate the impacts of these strong currents, monitoring surveys began later in the tide compared to downstream of the causeway when the stronger currents begin to subside. Gear deployment on the Kennetcook River typically commenced two hours prior to the posted high tide time for Hantsport (station 00282). As occurred near the Avon causeway in 2017 – 2018, several gear deployment sites were tested over the first few months until reliable sites were identified that could be fished consistently and repeatably (Figure 5). For example, initially, gillnets were deployed further upstream, then relocated to a more replicable site closer to the mouth for the remainder of the season. This configuration also reduced the spatial scale of fish sampling on the Kennetcook River to more closely align with sampling efforts on the Avon River.

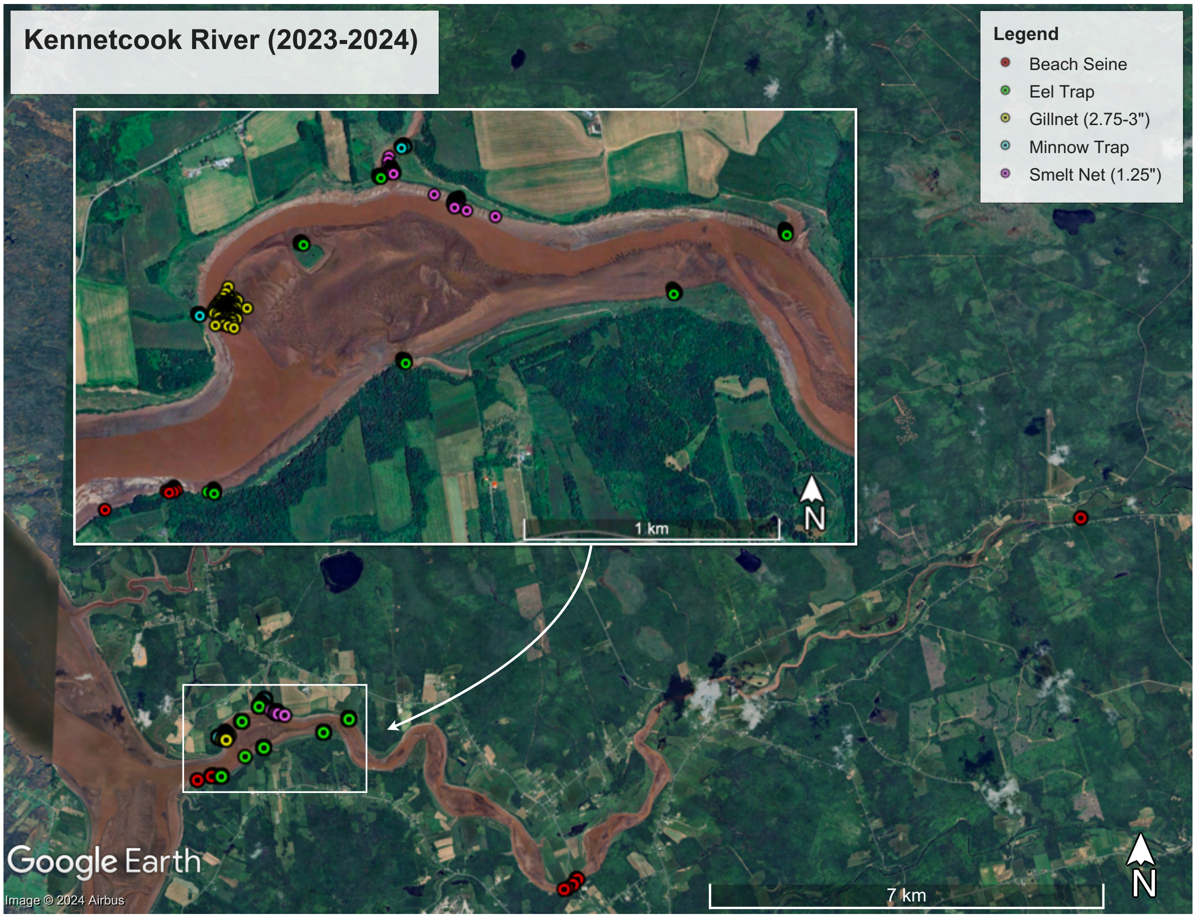

Figure 5 Fishing gear deployment on the Kennetcook River in 2023-2024.

4.1.2 PIT and T-Bar Tagging to Assess Passage, Survival and Detection Probability

4.1.2.1 Mark and Recapture

To provide further insight into individual movements and the level of fish passage provided by the structure, multiple species of fish were tagged with 12mm HDX passive integrated transponder (PIT) tags throughout the monitoring program to be uses in capture-mark-recapture analyses. PIT tags were inserted into the visceral cavity of fish using a needle and injector gun and species tagged to date have included alewife, American eel, American shad, Atlantic menhaden, Atlantic sturgeon, Atlantic tomcod, blueback herring, flounder, rainbow smelt, striped bass and white perch. All captured fish were scanned for tags using a Biomark HPR lite handheld scanner and any detected tags were recorded. Over time, recapture detections are used to determine the proportion of tagged fish detected to move through the causeway, providing an assessment of fish passage that is particularly useful for resident species such as American eel and Atlantic tomcod. Installation of PIT tag antennas in the Avon and Kennetcook Rivers will also provide enhanced resolution of tag detections and passage assessments, particularly for gaspereau.

PIT tag antennas were installed and tested in the Avon and Kennetcook watersheds in the fall of 2023 (Figure 6). Antenna arrays were constructed using 1 inch diameter PVC conduit and 10AWG, 104-strandcount wire wrapped once in each direction (two wraps total) to achieve an average detection range of approximately 1 foot in all directions from the pipe. Pipes were constructed to provide coverage in waters about 2 – 3 feet (1 m) deep, which satisfies many smaller tributaries and main rivers further upstream. Each deployment was configured as a single or multi antenna array using an ATC Autotuner and either an ORSR-1 Single Antenna Reader or HDX ORMR-1 Multi Antenna Reader and Control Center (Oregon RFID).

PIT tags have regularly been deployed upstream and downstream of the causeway and on the Kennetcook River since 2022. Since 2018 there have been 9,968 fish PIT tagged at the Avon causeway and 3,509 on the Kennetcook River. Collectively through studies carried out by this monitoring team on the Avon, Halfway, Cogmagun, Kennetcook and St Croix Rivers, 26,265 PIT tags have been deployed in the region, providing an opportunity to assess broader movements on a regional scale, including for the purposes of assessing cumulative effects, survival, and capture probabilities. Primarily gaspereau and striped bass have also been tagged with an external T-bar tag in hopes that commercial and recreational fishers would notice report the external tags. There have been 1904 T-bar tags deployed at the Avon causeway, 318 on the Kennetcook River and 3047 T-bar tags collectively deployed throughout the region since 2017. Occasionally external dart tags were used in place of T-bar tags; operationally they work the same, but dart tags remain embedded longer.

4.1.2.2 PIT and T-Bar Tagging Analysis

Marking fishes[1] (tagging) provides both a simple and advanced way to gather important information about movement, and survival and detection probabilities that are key factors to include in passage effectiveness and efficiency estimates and advanced capture-mark-recapture analyses. Analyses were done in complementary ways. First, movements between rivers, sites, and periods were tallied and visualized, and proportions of fishes caught to those available to be caught were found. Second, a preliminary capture-mark-recapture analysis was done to find survival and detection probabilities. All prior tagged fishes were considered regardless of where each was marked.

4.1.2.2.1 Recapture Rates

Proportions of fishes that were recaptured were tallied in two ways and represented recapture rates. First, in a simple tally of total fish marked and recaptured by years, not accounting for availability of marked individuals. Secondly, proportions were broken down based on year, capture site, and period to more realistically present marked fish that were available to be recaptured. For example, a fish marked in summer may not be available to be recaptured in spring. Sites were defined as upstream or downstream of barriers including barriers on the Halfway River and Avon River. The Halfway River barrier was included because fishes tagged upstream may not be available for recapture in subsequent sampling events, or, at least, will have a reduced probability of recapture. The Cogmagun, Kennetcook, and St. Croix Rivers sites were all defined as downstream because fishes tagged at those sites were freely able to move within the greater Avon Estuary. Years were defined as such, and periods were defined as arbitrary seasons based on prior fishes abundances and/or considering migration run times (periods when species take upstream migrations). Winter was defined as January and February, spring as April and May, summer from June to September, and fall from October to December; March was excluded because no sampling or tagging was done in March. Three important estimates were found:

1) An estimate of the proportion of fishes recaptured during any sampling event.
2) An estimate of the proportion of fishes moving between rivers.
3) An estimate of the proportion of fishes moving between barriers.

Assumptions of this analysis were as follows:

1) Fishes marked in any prior year or period were available to be recaptured in any future year or period.
2) Fishes marked in a current period were not available to be recaptured during that same period.
3) Fishes marked in any downstream site were available to be recaptured in any upstream site i.e. move across a barrier during, at a minimum, the next period.
4) Fishes marked in any upstream site were available to be recaptured in any downstream site i.e. move across a barrier during, at a minimum, the next period.
5) Fishes marked in any downstream site were assumed to be randomly mixed on every tide cycle.
6) Fishes marked in any upstream site were assumed to be randomly mixed each day because of the relatively small volume within which they reside.

Visualizations of recaptures were done to show movement patterns. Alluvial plots using package {ggalluvial} which is a {ggplot2} extension for producing alluvial plots in a {tidyverse} framework were used. These plots show start and end sites for individual fish with either PIT or T-bar tags. Fishes moving from one site to another provides an indication of passage effectiveness.

4.1.2.2.2 Survival and Detection Probabilities

Probabilities of survival and detection are important estimates for fisheries research. Fish do not live forever. Life expectancy and maturity occur at different ages based on species and are generally size related (Kuparinen et al. 2023). Therefore, either age or size can be important covariates in estimating probabilities in capture-mark-recapture analyses. The goal with this analysis is to estimate survival for fishes to use in spatial capture-recapture models. For this report, preliminary analyses are presented as a proof of concept that estimation is feasible. As such, traditional capture-mark-recapture models were run for species with sufficient encounter (capture) histories. Encounter histories are sequences of (usually) 0 and 1 designating if an individual was encountered (1) or not (0) during a sampling event. These encounter histories contain information about detection probabilities, survival, population abundances, and other parameters useful for modeling (Amstrup et al. 2005; Royle et al. 2014). Classical models that use mark-recapture include open population models using single (or multiple) Peterson-Lincoln or multiple Schnabel methods (Schnabel 1938; Darroch, 1958; Amstrup et al. 2005). Open models do not account for births, deaths, immigration, or emigration so are not suitable. Open population models account for these factors and the most common are based on the Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965) and have been extended to many specific model types since (Amstrup et al. 2005; Royle et al. 2014). Open population models are necessary because this study has multiple years of data and all four situations noted above will occur. Notable differences exist in models where some require knowing the number of marked individuals *and* the number of individuals caught (e.g. Peterson-Lincoln, Schnabel, and CJS) to get population size estimates, *N*.

4.1.2.2.3 Spatial Capture-Recapture Models

Advanced analysis methods are ultimately required for analyses of spatial capture-recapture (SCR) models that can include spatial processes (e,g, density, movement, and residency of individuals, environmental conditions) to extend traditional capture-mark-recapture models (Royle et al. 2014). The types of data currently being collected are suitable for SCR analyses. Spatial locations are recorded for each sampling event (fishing events such as trap and net locations), fishes are marked (tagged) with either PIT or T-bar/Dart tags and recaptured at future sampling events, environmental conditions (e.g. DO, temperature, salinity) are measured during sampling events and association data is available broadly or from loggers, and all fish (marked or not) are tallied during sampling.

The R programming software is ideally suited to conduct SCR modeling and extensive, well-maintained packages are available to accomplish these tasks. Ongoing analyses will use package {secr} (https://www.otago.ac.nz/density/SECRinR.html), capable of handling spatial movement, capture-recapture, and associated meta data including fish size (length), sex, and environmental conditions.

4.1.2.2.4 CMR Survival and Detection Probabilities

Many parameters are possible using capture-mark- recapture (CMR) models, but the core focus is generally to estimate survival, Phi, detection probabilities, p, and population size, N. Phi is defined at the probability of survival between capture (fishing) events. In this case, capture events occurred from 1 to 3 times per week at a given site. Most often twice per week during high migration periods (spring and fall) and once per week during summer. CMR models have underlying assumptions including the target animals (in this case fishes) are randomly mixed in the population between successive capture events and that each fish has an equal probability of capture (if alive). There are other assumptions, but these two are most important. Assuming that with each tidal cycle, most fishes in the Avon Estuary are concentrated to the limits of the tide. Fishes upstream of the Avon river causeway may or may not find their way below the causeway during a single tide cycle and be constrained to the upper river. The same is true of fishes that migrate to spawn in the upper river system; that is there is a period in which individual fish would not be ‘free’ to mix with the greater population. This complexity is currently not considered in the models specifically, but is considered in general in that models are based on ‘open’ populations where births, deaths, immigration and emigration are part of the model formula.

Models were run in Program MARK through the R interconnection provided by package rmark (Laake 2013). POPAN provides a parameterization of the Jolly-Seber model (Schwarz and Arnason 1996) in MARK. Schwarz and Arnason (1996) parameterized the Jolly-Seber model in terms of a super population (N), and the probability of entry. Probability of entry was not considered herein. N is estimated as part of the model, not derived from the model, and represents the estimated population size. Models were run using both monthly and yearly capture events to increase the probability of population mixing. In the case of yearly capture events, the probability of population mixing should be quite high given fishes either leave a watershed after spawning, or die. Capture events were set sequentially as each month, pooling all recaptured fishes by month; similarly for yearly capture events. There were 52 monthly capture events and 8 yearly capture events.

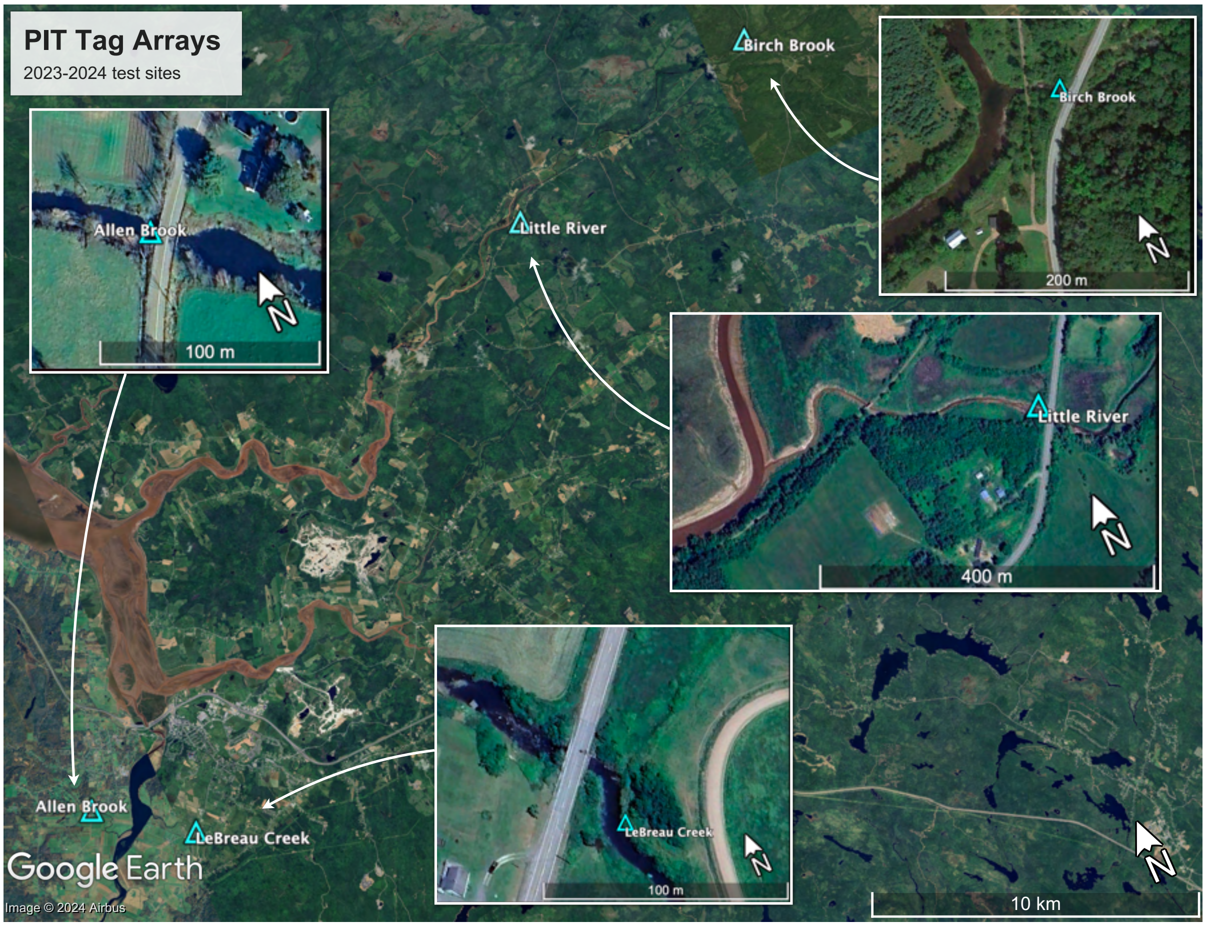

Figure 6 PIT tag array test deployment sites 2023-2024.

4.2 Results

4.2.1 CPUE and Visual Surveys

Summary CPUE figures are found in Appendix A – Summary CPUE and detailed figures plotting tide level, reservoir level, occurrence of gate openings, degree to which gates were opened and CPUE of American eel, Atlantic tomcod, rainbow smelt and striped bass can be found in Appendix B - CPUE With Gate Operations and Water Levels. Individual figures with gate operations are provided for each month, both upstream and downstream of the causeway and each figure includes data from 2018 to 2023 inclusive. First and foremost, fish passage physically cannot occur during times when both gates are closed. As such, even if gates are opened for 30 minutes near equalization, zero passage occurs for 91.7% of each 24hr period. Even under the ministerial order gates were closed after a minimum of 10 minutes of saltwater entry had occurred meaning zero fish passage occurred from shortly after mid tide, throughout high tide and until near mid tide on the outgoing tide. Open gates also do not automatically mean fish passage occurs. Suitable conditions including habitat characteristics, low enough downstream water velocities (head pressure) and the occurrence of a regular and sufficient ecological maintenance flow must be provided in order for fish to first be at the structure and secondly to facilitate safe passage.

It is clear that gaspereau do not pass through the causeway until the reservoir is dropped and that they pass most effectively under natural river conditions where gates are fully and consistently opened throughout the outgoing tide. Visual observations were recorded of gaspereau utilizing habitat throughout the Avon watershed under natural river state (Figure 7) and a large amount of young of the year gaspereau under 4cm total length were caught using a beach seine in 2023 (Table 4). The ratio of alewife to blueback herring was highest on the Kennetcook River and lower upstream compared to downstream of the Avon causeway in all years assessed (Table 5, meaning more alewife are observed on the Kennetcook, fewer on the Avon and fewest observed upstream of the causeway as compared to CPUE of blueback herring.

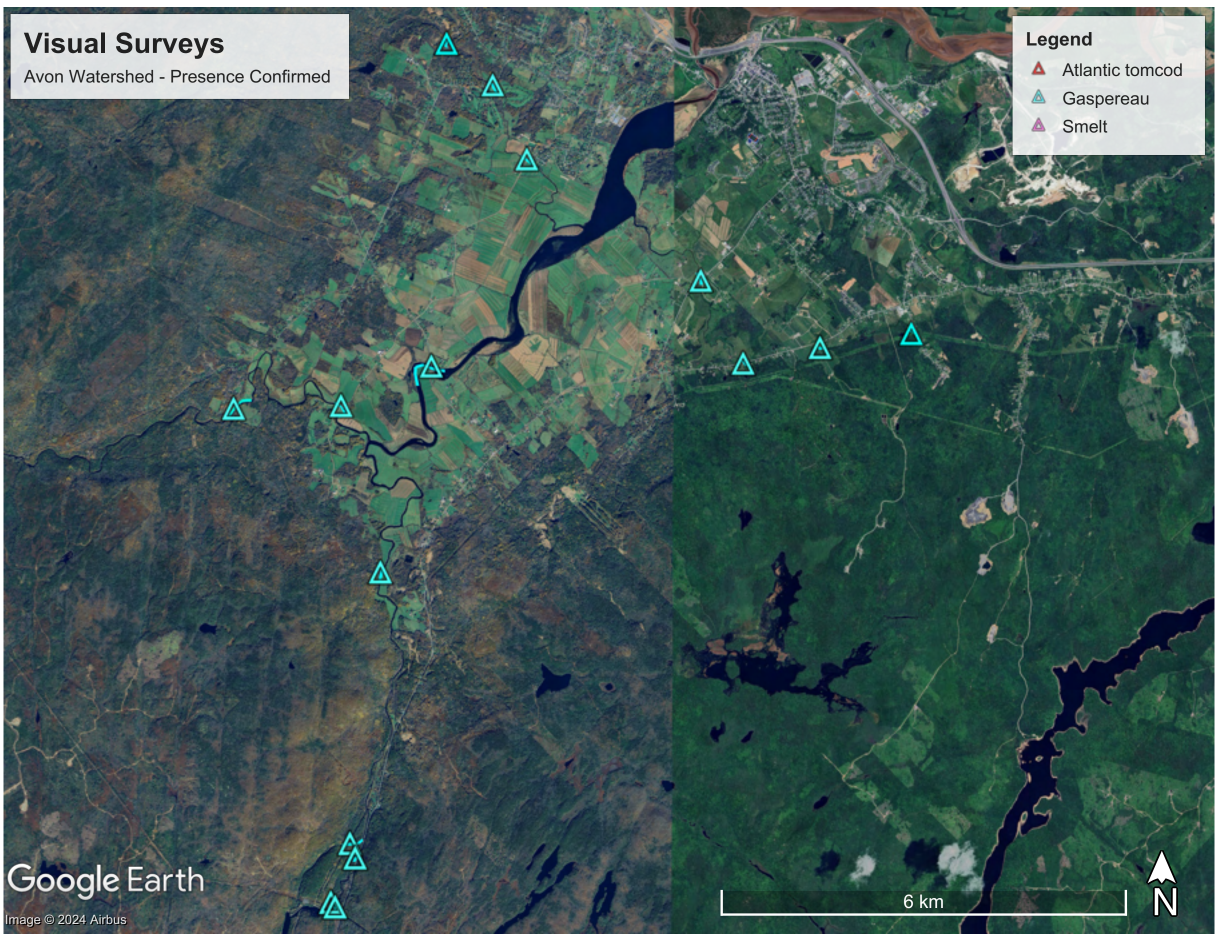

Figure 7 Confirmed presence of gaspereau in the upper Avon watershed through visual surveys.

Although observed only in very low abundances, rainbow smelt were only caught upstream of the causeway under natural river state with intentional saltwater entry, even though rainbow smelt were observed downstream of the causeway in each year of study. Further, only three young of the year smelt were caught with a beach seine downstream of the causeway while none were caught upstream. No visual observations of smelt have been made through this monitoring work upstream of the causeway.

While Atlantic tomcod were observed upstream of the causeway under reservoir conditions, it is believed that these observations were associated with occurrences of waters from downstream being allowed to enter upstream with the tide. Consistency and abundance of tomcod observed upstream of the causeway drastically increases when natural river state is provided with saltwater entry. Two Atlantic tomcod young of year were caught upstream of causeway on May 19, 2023 that were 2.5 and 3cm in total length. No visual observation of spawning activity have occurred on the Avon although spawning has been observed in the Kennetcook (Figure 8) and St Croix watersheds.

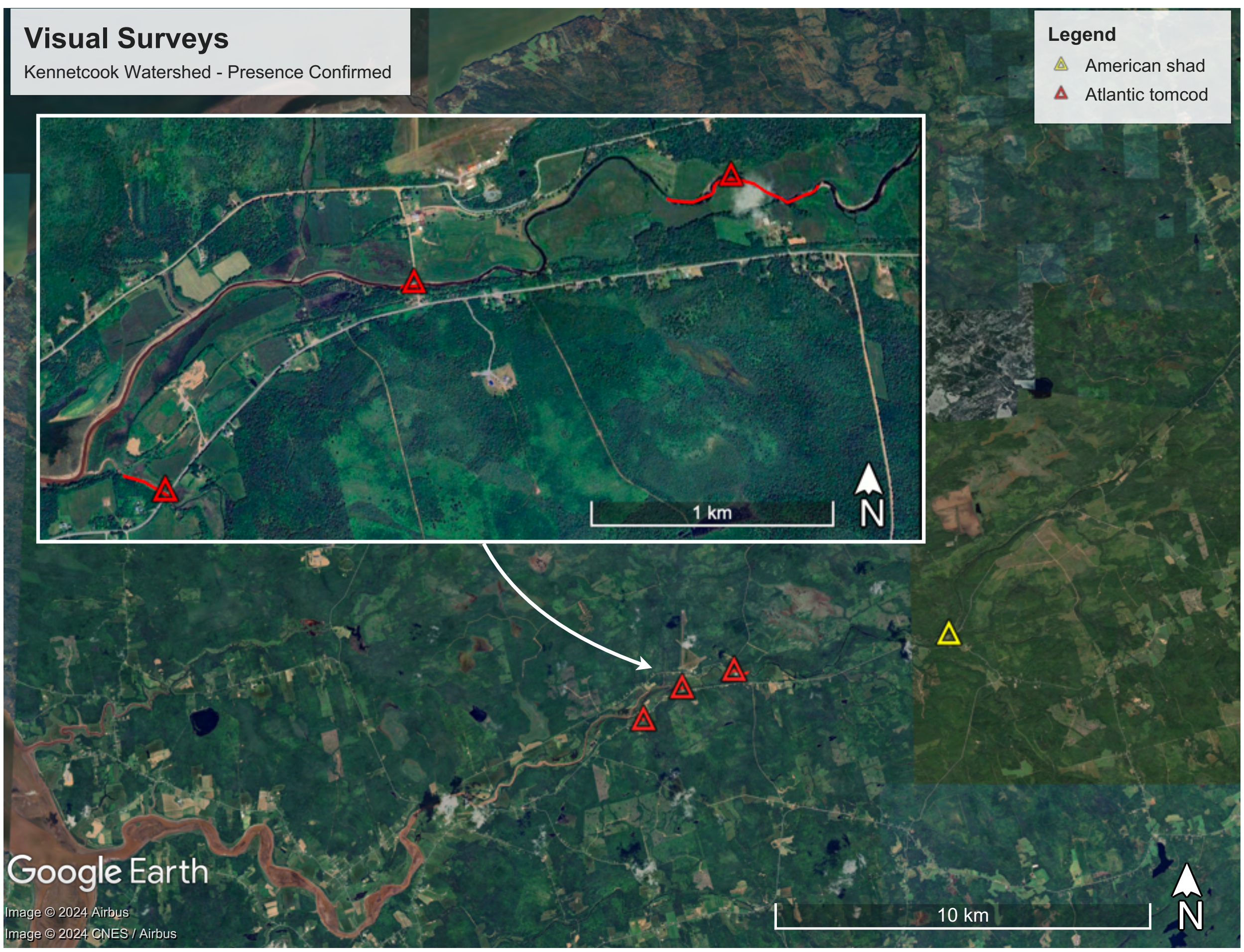

Figure 8 Confirmed presence of Atlantic tomcod and American shad in the Kennetcook watershed through visual surveys.

Table 4 Beach seine catch abundances 2023-2024

Species	Avon Upstream	Avon Downstream	Kennetcook River
American eel	21	3	62
Aquatic insect	201	0	5
Atlantic menhaden	0	2	28
Atlantic silverside	17	19	1582
Atlantic tomcod	2	20	98
Banded killifish	360	19	1
Brown bullhead	11	16	0
Chain pickerel	1	0	1
Creek Chub	0	0	0
Eastern blacknose dace	5	0	0
Flounder	3	0	7
Gaspereau	987	134	75
Green crab	1	0	32
Mummichog	373	51	23
Rainbow smelt	0	3	919
Sand shrimp	10	38	731
Smallmouth bass	8	0	0
Stickleback	131	10	12
Striped Bass	2	58	74
White sucker	0	0	1

Table 5 CPUE ratio of alewife to blueback herring.

Year	Avon Upstream	Avon Downstream	Kennetcook River
2022	1.07	2.12	9.24
2023	1.35	2.29	5.29

Striped bass begin appearing in the Avon system around late April as gaspereau abundances start to increase. While some striped bass were observed upstream of the causeway under reservoir conditions, striped bass passed more effectively through the causeway under natural river conditions. Striped bass <10cm in total length were caught in a beach seine on the Avon and Kennetcook Rivers starting in September but were never caught upstream of the causeway. Bigger striped bass generally left the system under warmer summer conditions and reappeared in fall when water cooled and abundances of Atlantic tomcod (prey species) began increasing. Striped bass were not observed in the vicinity of the Avon causeway past October when water temperatures likely became too cold.

While large data gaps exist in years prior to 2022, there was a few surveys conducted in the days after the reservoir was dropped in April 2020 where no American eel were caught, and a few weeks in June 2020 after the reservoir was maintained again where eel were caught downstream of the causeway but not upstream. These lack of catches suggest eel were either absent or not interested in feeding and so it is likely that the sudden change in habitat caused a temporary disruption to this species. It is also of interest that when considering all monitoring sites, American eel are typically observed first upstream of the causeway each spring and observed there last in the fall.

Atlantic silverside and flounder were caught upstream of the causeway using a beach seine in 2023, but only under natural river state. After the gates closed and a reservoir was maintained upstream of the Avon causeway, a transition occurred to largely freshwater or brackish species assemblages, including various aquatic insects (mosquito larvae, nymphs and water beetle, etc.), banded killifish, dace, mummichog, and stickleback (Table 4). Chain pickerel were observed in the reservoir and on the Kennetcook River in 2023 while smallmouth bass was observed only in the reservoir. There has also been a notable decrease in white sucker observed upstream of the causeway since 2017 where white sucker where only observed once in 2023. White perch abundances have also dropped notably on the Avon since a peak was observed in 2019 and 2020. White perch were only observed once in 2022 and not at all in 2023.

Adult Atlantic menhaden were first observed on the Avon River in this study on one occasion in 2021 followed by a large increase in 2022 and a drop again in 2023. A similar pattern was observed on the Kennetcook River in 2022 and 2023 suggesting this trend is unrelated to gate operations at the causeway. In 2023, numerous Atlantic menhaden with total length between 2 and 4cm were caught on the Kennetcook River while two individuals were also caught downstream of the Avon causeway. Atlantic menhaden was only ever observed upstream of the causeway on one occasion (and adult) in 2022. Although Atlantic sturgeon appear to rarely utilize habitat in close vicinity to the Avon causeway, one was observed downstream in 2017 and one was reported by commercial fishers in 2021. Evidence of sturgeon feeding was observed in the mud downstream of the causeway in 2022 but no evidence exists from this study to suggest Atlantic sturgeon have passed through upstream of the causeway.

At least one Atlantic salmon has been intercepted through this study every two years since 2018, either upstream or downstream of the causeway (one upstream in 2018, one upstream in 2020 and two downstream in 2022). Further, a salmon was reported downstream of Nova Scotia Power's Avon 1 dam in 2018 and another was caught by a recreational fisher in Lebreau Creek in 2019. In May 2023, a salmon smolt was intercepted near the mouth of the Kennetcook River through this study. DNA samples were taken on the salmon caught in 2022 and 2023 and submitted to the DFO Colebrook Biodiversity Facility for assessment. Results from the two salmon intercepted in 2022 were identified by DFO as being a 4-year-old salmon from a Live Gene Bank (LGB) cross in 2018 and a 5-year-old from a wild spawn at an unknown location between an LGB adult mother released in the Cornwallis River in 2017, and an unknown, unsampled father. These observations confirm that iBoF Atlantic salmon continue to utilize habitat on the Avon River and highlights the need to maximize passage through the causeway for this culturally significant and SARA listed species.

4.2.2 PIT and T-Bar Tag Recapture

Seven species had at least one fish recaptured with PIT tags within the greater Avon estuary (Table 6), and five species at least one with T-bar/Dart tags (Table 8). Table 6 and Table 8 show the decline in tag recaptures over time. Read each row separately. Each row is the number of fish tagged in a given year. Each subsequent year (recapture year) is the number of tag recaptures from the initial year in that row. Year = year of tagging, Number = number tagged that year and includes all fish tagged that year (it is not the total available fish with tags because fish die or move out of the system so all tags cannot simply be added up for other calculations. The CMR is designed to tease out the 'available tags' totals, but analysis has not progressed to that point yet. Recapture year = year of recapture. Within “Recapture” columns, the Year is the year of recapture. Numbers are X(Y) where X is the total recaptured with duplicate tags (that is, fish could be recaptured >1 times), and Y is the total recaptured of distinct (unique) fish tags. Because it is unknown how many tags are 'available' simply calculating proportions is not appropriate so these table outlines the 'decline in tag availability' because it tracks tags from the tagging year through subsequent years, but does not include 'new' tags added after the tagging year in the recapture year values.

Eight species were marked with PIT tags, but no fish were recaptured (Table 7). It is apparent that many fish need to be marked to get recaptures. All but one recaptured individual on the Avon River were detected though boat-based fishing. While PIT tag antennas were deployed in 2023, they were deployed outside the window in which most tagged species were likely to be detected at the array sites. A single detection of an American eel was obtained at the LeBreau Creek array. This eel was originally tagged just upstream of the causeway in June 2022 and recaptured in the same location in September 2023 before migrating upstream and into LeBreau Creek where it was detected on November 28, 2023. Given the time of year, this individual may have been using LeBreau Creek as an over wintering habitat. Deployment of arrays in time for the spring gaspereau migration will provide an opportunity to obtain a higher frequency of tag detections and now that the technical bugs have been worked out, arrays are expected to a valuable addition to the monitoring program in future years.

When fewer than 30–40 fish were marked, recaptures were ~3.7% at best. However, these recapture rates are based on all marked fish throughout all rivers within the Avon estuary for the current and previous years, which is not entirely realistic (see below). Recapture rates of 3–5 % are sometimes useful for simple calculations such as a two-sample Peterson-Lincoln population estimates, but the uncertainty associated with these simple calculations is large. More importantly, sufficient recaptures are necessary for advanced modeling to create encounter histories suitable for SCR models; many recapture histories, and multiple recaptures for some individuals, are required for robust analyses. Most tagged fish are recaptured only once, although some have been recaptured 10 or more times (Figure 22, Figure 23). Therefore, promising recapture data is available for American eel, Atlantic tomcod, and possibly gaspereau if both Alewife and Blueback herring are considered and PIT and T-bar/Dart marks are combined (Table 6, Table 7, Table 8). Similarly, combining PIT tagged and T-bar/Dart tagged striped bass would conceivably increase totals and provide more fish with encounter histories. However, most fishes tagged with T-bar/Dart tags were also PIT tagged. T-bar/Dart tags were used primarily to collect ancillary movement information from commercial (gaspereau) or recreational (striped bass) fisheries.

Recapture rates varied widely and were dependent on how many fish were marked and when they were marked (Table 9). This table depicts the mean +/- standard deviation and min/max for major sites (river and upstream/downstream) across all years (pooling data across years). This is an indication of the 'on average' proportion of recaptures recorded (as a percentage) of available tags in the estuary. To calculate proportions, the numerator is the total number of recaptures for a given year, site, and period (where period is spring, summer, fall, winter) and the denominator is all available tags in the system (all rivers and estuaries excluding Halfway River upstream – as it is unclear if those fish can return downstream) up until the prior period. For example, if 3 Alewife were recaptured in summer, then only tagged fish up until spring would be included in the denominator i.e. are 'available' to be recaptured. This ensures random mixing. Means +/- SD is calculated over all instances of the same species and considers combinations of year and site. In Table 9, n = number of year and site combinations that provide a recapture percentage. Mean +/- SD = mean proportion of recaptures of all tags available up until the prior period. These ignore years so ALL year and site combinations are used in calculating means. Min/max = min and max of the proportions.

Proportions were found by dividing recaptured fish from a specific year, site and period by all tagged fish available to be captured excluding fish within the current period. Further refinement of these rules is ongoing because fish marked on one day are conceivably available to be recaptured the following day. Summaries indicate six species were recaptured downstream of the Avon River, five upstream, and only three in the Kennetcook River with American eel having the highest recapture rates and variability (Table 9). Recapture rates were different between upstream and downstream for gaspereau, otherwise similar where species were caught in both sites. The proportion of times that recaptures were encountered was relatively low compared with the number of sampling events given Table 9 pools data across all years (2017–2023).

Alewife, American eel, Atlantic tomcod and blueback herring were all observed to move between rivers in 2023 (Figure 26). Several American eel and Atlantic tomcod were observed to move both from the Avon to the Kennetcook and St Croix Rivers, as well as from the Kennetcook and St Croix Rivers to the Avon. Both Alewife and blueback herring were observed to move from the St Croix to the Avon with no movement observed from the Avon to other rivers in 2023 for these species. American eel and Atlantic tomcod were detected to pass both upstream and downstream through the causeway while alewife and blueback herring were only detected to pass from upstream to downstream of the causeway (although it is clear through CPUE records that numerous individuals passed upstream at least under natural river state). American eel were only detected to have passed through the causeway 97 times since 2019 (noting that passage would have been poor in summer, fall and winter of 2019, 2020 and 2023 due to the impoundment of water upstream of the causeway) making analysis of passage difficult, especially under various operating scenarios. However, a very basic assessment (Table 10) shows that the majority of American eel remain on the side of the causeway where they were initially captured and tagged, while a much smaller proportion of eel are observed to move through the causeway.

While seven fishes had recaptured individuals, only four had enough data for models to run. Atlantic menhaden, rainbow smelt and American shad had too few marked individuals and too few recaptures resulting in models that did not converge on estimates. Even with many recaptured individuals, such as with gaspereau, preliminary models did not converge (Table 11). This result can happen when recaptures have long periods between them, or where detection probabilities (which is the probability or being recaptured) are low. Three species produced estimates of survival for at least yearly recapture events, and estimates were reasonable given what is known about each species (Table 11). Constant survival was used for all models, but monthly or yearly survival estimates are possible and were identifiable in models (not presented). Constant survival is essentially an 'average' estimate of survival across all months or years. The interpretation is a probability of an individual surviving to the next capture event so is predicated and driven by the period between recapture events. Detection probabilities work in the same way. Detection probabilities were very low in Atlantic tomcod and striped bass; and in the case of striped bass were likely the cause of unidentifiable estimates in monthly recaptures. Population size estimates for the greater Avon estuary, N, were variable depending on capture event intervals (month or year), and likely are sensitive to several factors inherent in CMR models. American eel N doubled when using yearly capture events over monthly, and Atlantic tomcod tripled. The sensitivities of all models, and adjusting model specifications to get models to converge, are currently ongoing, but the preliminary results show that CMR models are effective and provide key population dynamics metrics.

Table 6 PIT tag marked fishes with multiple recaptures by year of marking and year of recapture in the greater Avon estuary.

	PIT Marked		Recaptures						
Species	**Year**	**Number**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024[a]**
Alewife									
	2022	701	NA	NA	NA	NA	10 (10)	2 (2)	0
	2023	711	NA	NA	NA	NA	NA	9 (9)	0
American Eel									
	2018	182	91 (53)	21 (13)	18 (11)	21 (8)	4 (2)	1 (1)	0
	2019	5	NA	0	0	0	0	0	0
	2020	502	NA	NA	315 (168)	159 (87)	23 (8)	3 (3)	0
	2021	2077	NA	NA	NA	1138 (595)	573 (245)	58 (35)	0
	2022	1312	NA	NA	NA	NA	716 (401)	282 (149)	0
	2023	991	NA	NA	NA	NA	NA	380 (209)	0
Atlantic Menhaden									
	2021	23	NA	NA	NA	0	0	0	0
	2022	103	NA	NA	NA	NA	2 (2)	0	0
	2023	23	NA	NA	NA	NA	NA	0	0
Atlantic Tomcod									
	2020	1180	NA	NA	157 (135)	69 (58)	0	0	0
	2021	3813	NA	NA	NA	348 (306)	31 (28)	0	0
	2022	3788	NA	NA	NA	NA	233 (214)	29 (28)	0
	2023	3821	NA	NA	NA	NA	NA	272 (242)	4 (4)
	2024	11	NA	NA	NA	NA	NA	NA	0
Blueback Herring									
	2022	99	NA	NA	NA	NA	1 (1)	1 (1)	0

	2023	240	NA	NA	NA	NA	NA	3 (3)	0
Gaspereau									
	2020	184	NA	NA	37 (31)	1 (1)	0	0	0
	2021	472	NA	NA	NA	26 (23)	0	0	0
	2022	164	NA	NA	NA	NA	3 (3)	0	0
	2023	29	NA	NA	NA	NA	NA	1 (1)	0
Striped Bass									
	2020	33	NA	NA	NA	2 (2)	0	0	0
	2021	182	NA	NA	NA	6 (6)	0	0	0
	2022	185	NA	NA	NA	NA	4 (4)	0	0
	2023	136	NA	NA	NA	NA	NA	0	0

[a] 2024 monitoring to date only occurred in January.

Table 7 PIT tag marked fishes with no recaptures.

Species	Year	PIT Marked	Recaptures
American Smooth Flounder	2021	5	0
Atlantic Herring	2022	1	0
American Shad	2021	2	0
	2022	29	0
	2023	36	0
Atlantic Sturgeon	2022	1	0
Rainbow Smelt	2021	20	0
	2022	30	0
	2023	5	0
Skate	2021	1	0
White Perch	2018	11	0
	2022	1	0
Winter Flounder	2020	8	0
	2021	2	0
	2022	3	0

Table 8 T-bar/Dart tag marked fishes with year marked and years recaptured.

	T-bar/Dart Marked		Recaptures				
Species	**Year**	**Number**	**2017**	**2018**	**2020**	**2022**	**2023**
Alewife							
	2022	792	NA	NA	NA	8 (8)	1 (1)
	2023	781	NA	NA	NA	NA	4 (4)
Atlantic Menhaden							
	2022	102	NA	NA	NA	3 (3)	0
	2023	47	NA	NA	NA	NA	0
Blueback Herring							

	2022	122	NA	NA	NA	2 (2)	0
	2023	269	NA	NA	NA	NA	5 (5)
Gaspereau							
	2020	183	NA	NA	37 (32)	0	0
	2022	99	NA	NA	NA	1 (1)	0
	2023	105	NA	NA	NA	NA	1 (1)
Striped Bass							
	2017	27	1 (1)	0	0	0	0
	2018	30	NA	1 (1)	1 (1)	0	0
	2020	2	NA	NA	NA	0	0
	2022	171	NA	NA	NA	5 (5)	1 (1)
	2023	147	NA	NA	NA	NA	0

Table 9 Summary of PIT tag recapture rates.

River	Site	Species	n	Mean	SD	Min	Max
				%	%	%	%
Avon River							
	Downstream	Alewife	4	1.37	2.38	0	4.92
		American Eel	11	17.97	15.97	0	50
		American Smooth Flounder	2				
		Atlantic Menhaden	4				
		Atlantic Tomcod	11	0.55	0.67	0	2.27
		Blueback Herring	4	1.56	2.04	0	4.29
		Gaspereau	5	6.67	14.91	0	33.33
		Rainbow Smelt	1				
		Striped Bass	7	0.51	1.35	0	3.57
		White Perch	1				
	Upstream	Alewife	4	1.11	2.22	0	4.44
		American Eel	15	11.88	9.01	0	28.27
		Atlantic Tomcod	11	0.98	2.84	0	9.52
		Blueback Herring	4	3.33	6.67	0	13.33
		Gaspereau	6	0.56	0.9	0	2.04
		Rainbow Smelt	2				
		Striped Bass	7				
		White Perch	2				
		Winter Flounder	1				
Kennetcook River							
		Alewife	4	3.07	3.66	0	7.27
		American Eel	6	15.67	15.67	0	43.75
		American Shad	2				
		Atlantic Menhaden	2				
		Atlantic Sturgeon	1				
		Atlantic Tomcod	8	1.98	2.64	0	7.82
		Blueback Herring	4				

		Gaspereau	3				
		Rainbow Smelt	3				
		Striped Bass	5				

Table 10 Detections of American eel passing through the Avon causeway.

Year	Cumulative Tagged Eel at Avon Causeway	Number of Movements Detected	Portion of Tagged Eel with Movement Through Barrier	Number of Recaptures at Avon Causeway	Proportion of Cumulative Tagged Eel Recaptured
2018	182	-	-	92	0.51
2019	187	2	0.01	21	0.11
2020	330	18	0.05	73	0.22
2021	1272	22	0.02	493	0.39
2022	1839	29	0.02	589	0.32
2023	2314	26	0.01	394	0.17

Table 11 Estimated parameters from preliminary analyses of capture-mark-recapture data for seven fish species within the greater Avon estuary. All estimates are generated using capture events based on months. Values are probability (range 0 to 1) ± standard error. [LCL, UCL] contains LCL = lower 95% confidence limit, UCL = upper 95% confidence limit.

Species	**Capture events**	**Phi (survival, constant)**	**p (detection probability, constant)**	**N (estimated population size)**
Gaspereau (Alewife, Blueback Herring, and gaspereau combined)	Monthly	*Unidentifiable*	*Unidentifiable*	*Unidentifiable*
	Yearly	*Unidentifiable*	*Unidentifiable*	*Unidentifiable*
American Eel	Monthly	0.881 ± 0.0035 [0.874, 0.888]	0.077 ± 0.0023 [0.073, 0.082]	13,506 ± 258 [13,015, 14,028]
	Yearly	0.604 ± 0.013 [0.578, 0.629]	0.104 ± 0.005 [0.094, 0.115]	26,278 ± 1045 [24,327, 28,427]
Atlantic Tomcod	Monthly	0.954 ± 0.0020 [0.950, 0.957]	0.0045 ± 0.00019 [0.0041, 0.0049]	214,884 ± 8,244 [199,360, 231, 698]
	Yearly	0.709 ± 0.008 [0.692, 0.725]	0.0069 ± 0.0006 [0.0058, 0.0082]	752,170 ± 64,015 [636,964, 888,637]
Striped Bass	Monthly	*Unidentifiable*	*Unidentifiable*	*Unidentifiable*
	Yearly	0.685 ± 0.041 [0.601, 0.759]	0.0032 ± 0.0019 [0.0010, 0.0100]	87,281 ± 50,341 [30,750, 250,003]

4.3 Discussion

4.3.1 CPUE and Visual Surveys

While gaspereau can navigate upstream against moderate currents, the currents and heads pressure associated with maintaining a reservoir appears to be too strong to facilitate passage of gaspereau. Gaspereau may pass in low abundances if a reservoir is maintained only if the head pressure is sufficiently reduced, which most likely requires water from downstream being permitted to enter upstream so as to guide fish upstream through the culverts. For example, in 2019, reservoir conditions occurred for much of the spring although a drawdown of the reservoir did occur on several occasions but only for a very short period of time. Prior to May 21, 2019 only seven gaspereau and one striped bass had been caught upstream. In order for high abundances of gaspereau to be present and seeking upstream passage at the causeway, a sufficient and consistent downstream flow needs to be provided throughout the low tide period to not only keep these fish alive but also to attract fish into the Avon channel and upstream to the causeway. As such, the most effective passage of gaspereau observed occurs under natural river state with maximum saltwater entry. Visual observations of gaspereau utilizing all tributaries upstream of the Avon causeway under natural river state suggest that the reservoir is not required for successful spawning. This may be further supported by large quantities of young of the year gaspereau caught upstream of the causeway with a beach seine, although these catches did not occur until July meaning it cannot be certain whether these were the result of spawn under natural river state or reservoir conditions. However, gaspereau are two species (alewife and blueback herring) that prefer different spawning habitats. Alewife prefer lakes and pools while blueback herring prefer moving water. Habitat for both species exists under natural river state while additional alewife habitat would technically exist under freshwater reservoir conditions albeit passage to access that habitat is very poor. The artificial adjustments to habitat that occurred through various historical operations of the gated structure may have also artificially manipulated the ratio of alewife to blueback herring, which has unknown consequences. The higher ratio of alewife to blueback herring observed downstream of the causeway compared to upstream in 2022 and 2023 suggest that blueback herring are passing through the causeway more effectively than alewife.

In contrast to the three rainbow juvenile smelt beach seined downstream of the causeway, over 900 juvenile smelt were seined on the Kennetcook River and over 130 were seined on the adjacent St Croix River in 2023-2024. This suggests a lack of passage and a lack of spawning occurring on the Avon River.

While Atlantic tomcod have been observed upstream of the causeway during times when a reservoir was maintained, it is understood that passage was only provided when water from downstream was allowed to enter upstream of the causeway. Salinity data was not collected in 2019, although visual observations of murkier water were associated with Atlantic tomcod presence upstream of the causeway when a reservoir was maintained. In the fall of 2023, with a reservoir maintained, higher tomcod abundance upstream was largely observed during surveys where salinity was higher in the reservoir near the causeway. Note that when gates are opened to release water from the reservoir, the incoming tide of saltwater is kept further downstream (up to approximately one kilometer downstream of the causeway during higher rainfall or runoff events) by the resulting freshwater surge. As such, when 10 minutes of “saltwater entry” occurs during these events, the initial water entering upstream is mostly freshwater that was just released from upstream and so no or very little saltwater entry actually occurs on most days unless a longer period of tidal entry is permitted. It is possible that some tomcod may have remained in eddies downstream of the causeway and were carried upstream with freshwater re-entering the reservoir through the causeway. As such, it is understood that some Atlantic tomcod can pass through the structure if a reservoir is maintained, but only if water (especially saltwater) is allowed upstream through the causeway to push these fish through the culverts. Similarly to gaspereau, water conditions need to be suitable downstream for fish to enter and survive in the channel meaning sufficient and consistent downstream flows need to be provided through the structure during the low tide period. Atlantic tomcod were observed to pass through the structure when the reservoir was dropped to provide natural river state and most effectively under increased saltwater entry during prolonged natural river state conditions. Considerable rainfall or runoff events also appeared to hinder passage of Atlantic tomcod, likely due to strong flows caused by narrowing of the river through the culverts that appear to have flushed tomcod out of the area. Two young of the year Atlantic tomcod caught upstream of the causeway under natural river conditions in May 2023 may suggest successfully spawning upstream of the causeway although this may have simply been a result of Atlantic tomcod dispersing from nearby rivers where spawning activity has been documented (Kennetcook and St Croix watersheds).

Striped bass passage is influenced by prey abundance and water temperatures. Striped bass follow prey species and so if passage is provided and an abundance of prey species are found above the causeway as occurs best under natural river state, striped bass were usually also found, temperature dependant. Striped bass likely also take advantage of build ups of prey fish seeking passage when gates are closed, and so CPUE may increase upstream or downstream of the structure depending on the direction most fish are migrating and being disrupted by gate closures. Larger striped bass generally appear to prefer cooler temperatures in this system while smaller bass can typically tolerate warmer waters, which may be a survival tactic of smaller fish to avoid predation by larger fish.

American eel reside in estuarine and freshwater environments and so populations have likely been established both upstream and downstream of the causeway. As such, CPUE does not directly reflect passage for this species. However, CPUE does reflect that large and fast changes in habitat caused by different gate operations does have a temporary impact on American eel. The uniquely long temporal catch window of the American eel season upstream of the causeway compared to other local sites is of interest and while it may be a result of temperature differences between sites, it may also suggest the presence of important overwintering habitat in that area.

Freshwater species such as brown bullhead, white sucker and even beaver were observed immediately downstream of the causeway on several occasions since 2017. This region frequently transitions between estuarine and freshwater habitat depending on how much water is released downstream and how long gates are open on the incoming tide. Such occurrences most likely demonstrate involuntary passage of individuals being flushed downstream and could result in mortality events if there is an inability to return to suitable habitats. The notable decrease in white sucker observed upstream of the causeway since 2017 and in white perch since a peak was observed in 2019 and 2020, further suggest that changes in gate operation have led to changes in habitat in the immediate vicinity of the causeway within recent years.

Particularly in 2022, weir operators within the Minas Basin reported being overwhelmed by Atlantic menhaden (Darren Porter, pers. comm.), providing evidence that their abundance increased and/or their range expanded in this region in 2022. Further monitoring will be useful in determining if Atlantic menhaden have become seasonal residents of the region and how that may change the spatial and temporal patterns of other species such as striped bass, given the potential for Atlantic menhaden to serve as a prey fish. Note that Atlantic menhaden spawn in coastal systems and not typically in estuarine areas meaning they are utilizing the area for primarily for feeding (NOAA 2023). As filter feeders, Atlantic menhaden primarily consume phytoplankton and zooplankton (NOAA 2023) and so a lack of observed passage through the structure may be an indication of an unbalanced ecosystem upstream of the causeway where a sufficient supply of food may not be available.

Atlantic sturgeon have a suctorial mouth and buccal cavity and feed by vacuuming whatever species are available in the local benthos (COSEWIC 2011). As such, sturgeon typically prefer soft substrates and rely on feeding habitats in estuaries with a healthy and stable benthic community. Atlantic sturgeon are much more common on the Kennetcook and St Croix Rivers where waterflows are much more consistent and thus more able to provide and maintain a stable benthic community. The inconsistent flows observed under reservoir conditions do not appear to provide stable conditions for a healthy benthic community (freshwater or esturine) to establish, whereas flows under natural river state appear to allow enough stability for a benthic community to begin developing, as suggested by reports of sturgeon caught downstream of the causeway in 2021 and evidence in the downstream mud of feeding activity in 2022.

The interception of four Atlantic salmon at the causeway since 2018 is strong evidence of a persistent presence of this species in the Avon system. Further, the genetic assessment by DFO staff that the two salmon intercepted downstream of the causeway in 2022 have direct ties to the LGB program (as well as an unknown, unsampled male) confirms that a *SARA* listed species continues to interact with the Avon causeway. These observations stress the need to maintain the flow of water necessary to permit the free passage of fish and maintain at all times the characteristics of the water and the water flow downstream of the causeway that are sufficient for the conservation and protection of the fish and fish habitat so as to avoid killing, harming or harassing this *SARA* listed and culturally significant species. The definition of death of fish includes not only direct death but also prohibiting fish from carrying out their life processes. Given that the nutrient transfer provided through spawning migrations, movement of freshwater mussel through gills and other phenomenon that impact fish habitat are dependent on fish having access to that habitat, the blockage of fish passage is considered to have an impact on the habitat itself and can therefore be considered a Harmful Alteration, Disruption or Destruction (HADD) of fish habitat. Gate operations that maintain a reservoir are causing damaging effects to fish passage and fish habitat and are not authorized under *SARA* or the *Fisheries Act*.

4.3.2 PIT and T-bar Tag Recapture

Recaptures were frequent across fishes, but infrequent when few fish were marked and when sampling events decreased. Coupled with fish deaths, emigration, and removal by commercial and recreational fisheries, maintaining a sufficient sampling effort is imperative to collect sufficient and quality data for the various analyses. Recapture rates are affected by the natural processes of population dynamics and from anthropogenic activities. The available marked fishes in the system decline rapidly when additional fishes, and enough of them, are not marked; therefore, at least yearly marking is important. The reasons for a variable recapture rates are severalfold and all intertwine with metrics being used and adopted for analyses. Fish die and species have different life histories and ages when they do so. Fish are removed from the system by commercial (gaspereau) and recreational fisheries (striped bass); although only a few species are impacted by each, they are important ecologically. Population sizes are likely high for some species, and immigration and emigration occur at unknown rates. Some of these vital rates will be estimates with SCR analyses and provide parameters helpful in modeling. Additionally, some species are transient (e.g. striped bass) or undertake mass migrations (e.g. gaspereau, Atlantic tomcod, rainbow smelt) moving through the system at various times to support various lifecycles. Some species stray (e.g. gaspereau) with estimates of straying rates available from other studies (Andrews 2014, Gregoire 2020), and some movement patterns are largely unknown such as Atlantic tomcod. Finally, American eels spend many years in the same area and are facultative diadromous meaning although the general life history is to spawn in the Sargasso sea, eel lifecycles are much more variable. Proportions of the eel population spend the majority of time in fresh water, salt water, or moving between both (Pavey et al. 2015). Therefore, interpretation of recapture rates varies by species.

A high degree of connectedness was observed between the Avon, Kennetcook and St Croix rivers in 2023. While American eel and Atlantic tomcod were both observed to move between the Avon and the St Croix, more of both species were observed to move from the Avon to the St Croix in 2023 which may be a result of increased tags deployed in the system. Installation of PIT tag arrays in the spring would provide better insight into the proportion of gaspereau that may seek alternative spawning habitat if passage is not provided at the Avon causeway.

4.4 Gaps and Lessons Learned

Passage is minimal under freshwater reservoir conditions, slightly improved through allowance of saltwater entry and greatly improved when natural river state and saltwater entry is provided.

Tagging and detection data is needed to assess passage of American eel. The quantity of movement detections through the causeway is currently limited (97 detections since 2019).

Sufficient recaptures are necessary for advanced modeling to create encounter histories suitable for SCR models; many recapture histories, and multiple recaptures for some individuals, are required for robust analyses. As such, sufficient monitoring surveys need to be carried out to not only deploy a sufficient quantity of tags but to also provide opportunity to collect a sufficient quantity of tag recaptures.

14mm HDX PIT tags have much better read range for antennas, especially in brackish water. These will be utilized over 12mm tags moving forward. Substantial collaboration between Acadia University and Oregon RFID is being undertaken to evolve PIT tag detection technology and make it effective in estuarine regions. PIT tag antennas provide a higher resolution of detections than capture-mark-recapture through CPUE but require time to order, build and install equipment and ensure staffing is in place to maintain arrays. Now that the technical bugs have been worked out, deployment in future years is expected to be much more efficient.

The black box containing a car battery and PIT tag reader box was stolen from the Allen Brook PIT tag array site between October 26 and October 28, 2023. A trail camera was installed there but it could only be placed in certain locations to avoid being stolen as well and unfortunately the camera at the Allen Brook site did not capture the theft. To address this, cellular trail cameras were positioned on the Avon sites to automatically send an image to a phone if someone were to steal the camera or any gear. Tile tags were also installed in each battery box to enable tracking of stolen gear. If gear was stolen and the Tile came in close enough contact with a phone, a notification would be sent to the team to enable the recovery of gear.

5.0 Objective 3 - Assess Efficiency of Fish Passage

5.1 Methods

5.1.1 Damage and Mortality Assessments

In 2020 and onward, any visual evidence of physical damage to captured fish was recorded and when time permitted, a representative photograph was taken with the time of that photograph recorded to document the damage. Not every fish was photographed, but every fish was assessed for damage. If damage was observed, it was categorized as abrasion, hemorrhage, wound, eye, prolapse, swim bladder, mortality or predation, or a combination thereof when entered into the data base. In 2022 and onward, an assessment of parasites was conducted on each fish for ich, black spot disease and lice. Note that more injured or diseased fish may not have been able to actively enter traps or may not have been intercepted by nets. Further, deceased fish may have sunk and gone undetected. As such, all damage assessments must be interpreted as minimums.

5.1.2 Assess Delays in Fish Passage

Comparison of the mean CPUE observed upstream compared to downstream of a barrier over the year also provides an estimate of passage efficiency. If a significant difference is observed, it may suggest that a build-up of fish is occurring on one side of the barrier, which would be indicative of a restriction to fish passage. A similar mean CPUE observed upstream and downstream of a barrier would suggest fish are able to pass through with minimal delay.

A "run time" calculated for key representative species using annual CPUE data provides an opportunity to compare the duration over which a particular species is utilizing habitat or seeking passage between sites or from one year to the next (between different gate operations). For example, a significant difference in the number of days contained within the run time of migrating fish such as gaspereau between natural river state and reservoir conditions would suggest a change in the efficiency of the passage. A change in the run time of predators such as striped bass may suggest a change in passage or habitat conditions for prey species.

5.1.3 Acoustic Tagging to Assess Fish Behaviour and Passage Attempts

In 2023-3034, the CMM, Darren Porter, Acadia University and CBCL worked with Innovasea (located in Bedford, NS) to design and test a means to deploy acoustic receivers at the Avon causeway. It was hypothesized that deployment of four receivers at each site (two mounted higher and two mounted lower) would provide sufficient capabilities to determine an x-y position of an acoustic tag, and by using pressure tags, an x-y-z position could be determined for these tags. Innovasea also recommended testing of two different frequencies, the commonly used

180 kHz system and a newly developed 307 kHz system designed for higher noise environments such as power generation facilities. Note that the 180 kHz system has pressure sensor tags available but the 307 kHz system does not, and so an x-y-z position would only be possible using the 180 kHz system. On January 4, 2024, HR2 (180 kHz) and HR3 (307 kHz) receivers were deployed downstream of the Avon causeway (Figure 9) to assess several questions:

1) Is the CBCL mounting technique sufficient for long term deployment of receivers?
2) If and when in a tidal cycle can acoustic tags be detected at the causeway?
3) Does the 180 or 307 kHz system perform better than the other?
4) Is the data obtained sufficient to justify including an acoustic program in the monitoring plan?

As part of this acoustic test, a V9TP-2x-180k-3 (180 kHz) and V3 (307 kHz) tag was taped to a rope and buoy and moored to the centre column of the gated structure to act as sentinel tags (Table 12). These tags were left in place for the duration of the test to determine when in the tidal cycle tags could be detected. During fish monitoring surveys, a second set of tags was towed by boat while recording a GPS track to further determine how well the receivers could determine a tags position (Figure 10). A range test was also conducted where a set of tags were temporarily placed in the water at known distances from the receivers and at two different tide heights to assess how far away receivers could detect tags. The receivers and test tags were removed from the causeway on January 24, 2024. Detection data was subsequently downloaded and submitted to Innovasea for analysis.

Table 12 180 kHz test tag specifications.

Tag Family	VUE Tag ID	Step 1 Time (dy hr:min:sec)	Step 1 Power (L/H)	Step 1 Min Delay (sec)	Step 1 Max Delay (sec)	Loop To	Sensor type	Range	Units	NOTES
V9TP-2x-180k-3	A180-1704-1080	14 00:00:00	H	18	22	2	T	-5 to 35	°C	TOWED BY BOAT
V9TP-2x-180k-3	A180-1704-1081	14 00:00:00	H	18	22	2	P	17	Meters	TOWED BY BOAT
V9TP-2x-180k-3	H170-1803-1080	14 00:00:00	H	1.8	2.2	2	T	-5 to 35	°C	TOWED BY BOAT
V9TP-2x-180k-3	H170-1803-1081	14 00:00:00	H	1.8	2.2	2	P	17	Meters	TOWED BY BOAT
V9TP-2x-180k-3	A180-1704-1082	14 00:00:00	H	18	22	2	T	-5 to 35	°C	MOORED TO CAUSEWAY
V9TP-2x-180k-3	A180-1704-1083	14 00:00:00	H	18	22	2	P	17	Meters	MOORED TO CAUSEWAY
V9TP-2x-180k-3	H170-1803-1082	14 00:00:00	H	1.8	2.2	2	T	-5 to 35	°C	MOORED TO CAUSEWAY

V9TP-2x-180k-3	H170-1803-1083	14 00:00:00	H	1.8	2.2	2	P	17	Meters	MOORED TO CAUSEWAY

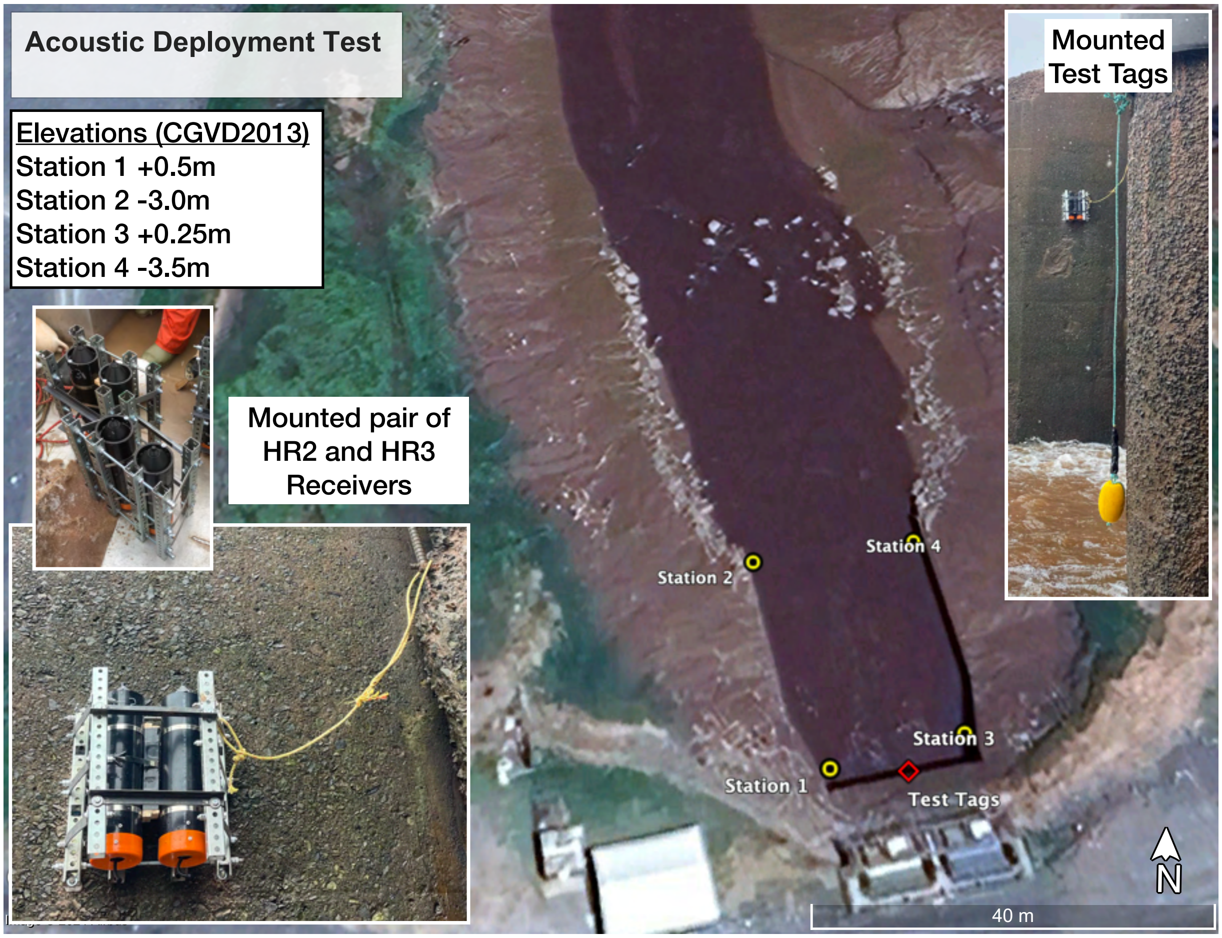

Figure 9 Mooring locations, mounting technique and range test locations of Avon causeway acoustic trial.

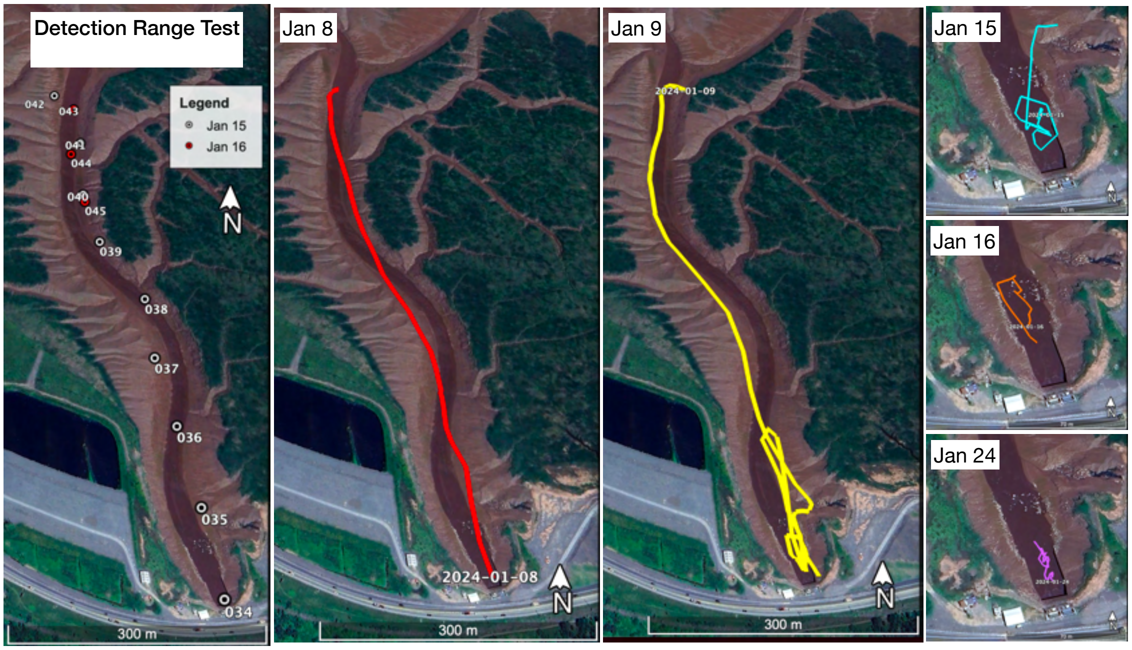

Figure 10 Test tag tow maps, January 2024.

5.2 Results

5.2.1 Fish Damage and Mortality

Figures outlining overall fish damage and species specific figures for gaspereau, Atlantic tomcod, striped bass and American eel are shown in Appendix D - Fish Damage. In 2023, overall damage was observed to be highest upstream of the causeway (21.18%) and notably lower on the Kennetcook River (13.58%) and downstream of the causeway (13.09%). Overall damage was higher upstream of the causeway compared to previous years at all sites. Changes from the previous year also include an overall reduction in observed hemorrhage and prolapse but more observations of wounds and abrasion.

In 2020, much of the observed damage in gaspereau occurred after the reservoir was established and in 2023, half of the surveys where damage was observed in gaspereau (including the survey with the highest percentage of damage observed) occurred after the reservoir was established. The percentage of gaspereau observed to be damaged upstream of the causeway under natural river state was low in 2021 (1.29%) and zero in 2022 compared to 13.8% in 2020 and 11.14% in 2023. Downstream of the causeway, damage in gaspereau was 8.92% in 2020, fell in 2021 under natural river state but increased in 2022 (to 6.25%) based on data collected on one survey. No damage was observed in gaspereau downstream of the causeway in 2023.

Noting that monitoring did not occur in fall 2020, the highest percentage of Atlantic tomcod observed to be damaged occurred in 2023, upstream of the causeway (53.85%). Damage was least in 2021 and 2022 under natural river state (23.2% and 24.81% respectively). Damage was similar downstream of the causeway and on the control site (Kennetcook River) in 2021 but lower downstream compared to the Kennetcook in 2022. The increase in damage in 2023 was associated with a decrease in prolapse and hemorrhage but an overall increase in abrasion and wound.

Overall, damage in striped bass decreased from 2022 to 2023 although observations of damaged striped bass have been comparatively few in each year of study. Damage observed in striped bass appears to have contributed considerably to the total damage observed in 2022 upstream of the causeway while interestingly, no striped bass have been observed damaged on the Kennetcook River.

Monitoring of American eel did not occur for large portions of 2020 and 2021, although a full set of data are available for 2022 and 2023. A large increase in damage was observed upstream and downstream of the causeway under reservoir conditions and gate openings near equalization in 2023 compared to natural river state in 2022 (from 5.08% to 24.71% upstream and 7.46% to 16.44% downstream). This increase in damage is associated with increases in both abrasion and hemorrhage.

5.2.2 Delays In Fish Passage

Boxplots comparing mean CPUE between upstream and downstream of the causeway for key species are shown in Appendix E - Comparison of mean CPUE Between Upstream and Downstream of Causeway and summarized in Table 13. First and foremost, fish passage cannot occur if gates are closed. Fish also need suitable conditions including habitat characteristics, low enough downstream water velocities (head pressure) and the occurrence of a regular and sufficient ecological maintenance flow in order to first be at the structure to seek passage and secondly to be provided the ability to pass safely. If fish passage is not effective, it cannot be efficient.

Although gaspereau has been observed upstream of the causeway in all years, the only years when mean CPUE was higher upstream of the causeway compared to downstream was in 2021 and 2022 when natural river state occurred with considerable and intentional saltwater entry. In 2017, 2018 and 2020 natural river state occurred for a considerable portion of the gaspereau migration (but not all), although little to no intentional saltwater entry was believed to have occurred. In 2018 and 2020 data provided by the NSDA shows that natural river state occurred only from late April until June with much more consistent openings occurring in 2020. Mean CPUE in 2017 and 2018 was observed to be notably higher downstream of the causeway compared to upstream while in 2020, the mean CPUE was more similar upstream and downstream of the causeway. In 2019, a reservoir was maintained for nearly the entire gaspereau migration meaning gates were largely closed and a sufficient ecological maintenance flow did not occur. Note that sampling did not begin until late May downstream of the causeway and until mid-April upstream in 2019 resulting in considerable data deficiencies. However, significantly less gaspereau were observed upstream of the causeway compared to all other years of study showing that passage was overall poor in 2019. In 2023 natural river state occurred alongside saltwater entry until June, resulting in a higher mean CPUE downstream of the causeway but the difference between the two sites was less extreme than in years when regular gate openings and saltwater entry did not occur.

Rainbow smelt were only observed upstream of the causeway in 2017, 2021, 2022 and 2023, and largely in correspondence with natural river state and intentional saltwater entry. Although monitoring gaps occurred in 2019, it appears little to no passage occurred for rainbow smelt in

2018 through 2020 during which various conditions occurred ranging from freshwater reservoir to natural river state with no intentional saltwater entry. It is unclear if the higher mean CPUE observed upstream of the causeway in 2023 is a result of improved passage or that this was a reflection of higher variability in CPUE of a species present in low abundance.

The mean CPUE of Atlantic tomcod has been considerably higher downstream of the causeway in all years of study, even under natural river state with intentional saltwater entry. Note that considerable data gaps occurred during the Atlantic tomcod migration window in 2017, 2018 and 2020; however, the mean CPUE upstream of the causeway is higher during years when saltwater entry occurred and highest during natural river state with intentional saltwater entry. It is of interest that CPUE of Atlantic tomcod was observed to drop off considerably upstream of the causeway and near the causeway on the downstream side during high freshwater runoff events where it appears currents increased by the narrowing of the river through the culverts are flushing Atlantic tomcod downstream and so passage conditions are particularly ineffective during those times. Such occurrences are most common in the spring and late fall when the highest abundances of Atlantic tomcod are observed within the upper estuarine ecosystems.

The mean CPUE of striped bass was highest downstream of the causeway in 2019 when reservoir conditions existed, presumably resulting in a large buildup of gaspereau downstream of the causeway seeking upstream passage. In 2020, a large increase in the CPUE of striped bass was observed downstream of the causeway after gates were closed and a reservoir was maintained. In 2021 and 2022 when the mean gaspereau CPUE was higher upstream of the causeway, the mean CPUE of striped bass was also highest upstream.

American eel has been caught with a higher mean CPUE downstream of the causeway in all years, especially 2020 and 2021 although data may be skewed by a lack of surveys occurring later in 2020 when eels are typically not caught. It is important to note that American eel naturally reside in both fresh and estuarine environments, meaning a resident population most likely exists upstream and downstream of the causeway and a difference in mean CPUE may not necessarily be attributed to specific conditions of fish passage.

Table 13 Mean CPUE by site and year for key species.

Site	2017	2018	2019	2020	2021*	2022*	2023*
Gaspereau							
Avon Upstream	27.76	17.79	8.03	53.37	56.4	20.81	25.83
Avon Downstream	73.2	66.91	26.7	60.6	36.63	20.7	32.85
Kennetcook River	-	-	-	-	-	5.26	0.05
American eel							
Avon Upstream	27.76	17.79	8.03	53.37	56.4	20.81	25.83
Avon Downstream	73.2	66.91	26.7	60.6	36.63	20.7	32.85
Kennetcook River	-	-	-	-	-	2.21	2.34
Atlantic tomcod							
Avon Upstream	0.32	0	0.63	0.56	2.73	5.18	1.74

Avon Downstream	4.36	1.73	15.1	4.89	13.31	13.43	11.68
Kennetcook River	-	-	-	-	-	6.96	9.72
Rainbow smelt							
Avon Upstream	0	0	0	0	1.28	0.33	1.42
Avon Downstream	3.7	1.4	0.48	1.82	1.69	2.33	0.79
Kennetcook River	-	-	-	-	-	0.43	0.46
Striped bass							
Avon Upstream	0.5	0.45	0.62	2.67	5.12	2.85	4.08
Avon Downstream	2.86	2.06	5.8	5.24	2.38	1.89	4.08
Kennetcook River	-	-	-	-	-	1.29	1.74

	Natural river state occurred throughout migration window
	Natural river state occurred for most of migration window
	Reservoir maintained during most or all of migration window
*	Years when salt water entry was mandated

5.2.4 Delays in Migration

The run time or catch window showing the annual variability in the period during which key species are caught is provided in Appendix F - Comparison of Migration Windows by Species. Although the catch window or time frame during which the majority of gaspereau were caught each year includes all life stages and was observed to vary, the migration of gaspereau >20cm in total length typically occurs from mid-April to early June. However, in 2019 when reservoir conditions occurred for much of the spawning period, the migration window or time over which gaspereau were caught was notably extended well into late July. Young of the year gaspereau were first targeted in 2023 and were caught in much higher abundances during reservoir conditions upstream of the causeway compared to other sites and for a much longer time period (Figure 11).

The catch window of rainbow smelt is highly variable in part due to a low abundance and that in some years, smelt were caught for a period in both the spring and fall. Significant data gaps exist during the Atlantic tomcod migration in a number of years prior to 2022 and so an assessment of run time relative to gate operational scenario is difficult to decern, although the overall run time in 2022 was shorter compared to 2023. After considering data gaps, particularly in 2020, the beginning and end of the catch window for American eel appears largely temperature dependant with warmer water in spring corresponding to an earlier emergence and eels being caught longer into fall in years where the water was warmer.

The run time of striped bass largely follows the run time of prey species, especially gaspereau in the spring. Similarly to gaspereau in 2019, striped bass run time began later in 2019 at the causeway than in other years although the run time of striped bass was shortest in 2019 and longest in 2018 and 2023.

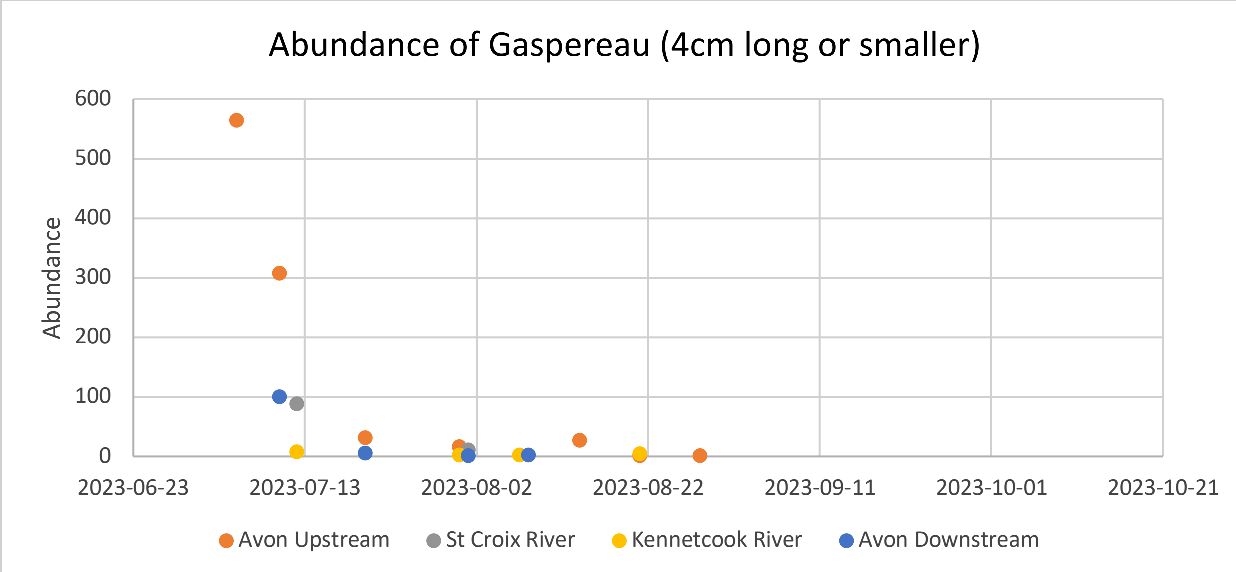

Figure 11 Abundance of gaspereau (less than or equal to 4cm TL)

5.2.3 Acoustic Tagging

Innovasea's report on their analysis of acoustic test data is available in Appendix G – Acoustic Trial. Note that detection data was filtered using gate operation and tide level data provided by the NSDA to show time periods for when the receivers were submerged.

1) Is the CBCL mounting technique sufficient for long term deployment of receivers?

CBCL's mount design and installation worked well, although some mounts were slightly bent and many of the hose clamps had snapped after only a month of deployment. Some adjustments to strengthen these moorings will be required, especially for long term deployments.

2) If and when in a tidal cycle can acoustic tags be detected at the causeway?

At a maximum, the detection window is limited to when receivers are submerged (Figure 12). Two receivers are mounted lower in elevation than the others to help facilitate triangulation (positioning) and so determining an x, y position of fish is only possible when three receivers are submerged, which occurs on the incoming tide from near mid-tide to high-tide and then on the falling tide from high-tide to near mid-tide (a period highlighted in green, approximately 6 hours). A tag need only be detected by one receiver to confirm presence of a tagged individual and because a z position is determined using a pressure sensor within the tag, the presence and depth of a fish may be obtained during times when at least the lowest elevation receiver is submerged (periods highlighted in green and white, approximately 8 hours). Detections of tags are not possible when all receivers are not submerged (near low tide), which is highlighted in red and lasts for a period of approximately 3 hours.

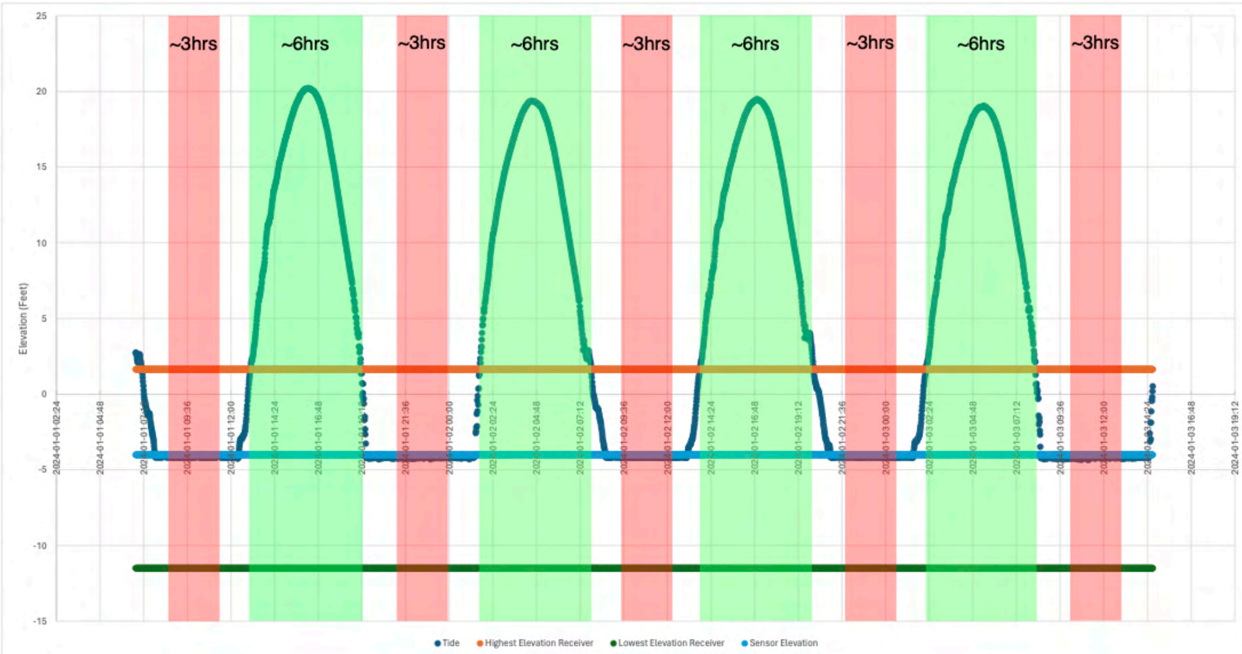

Figure 12 Sample of receiver detection windows downstream of the Avon causeway.

3) Does the 180 or 307 kHz system perform better than the other?

Innovasea's analysis and report shows that the 307 kHz frequency has a higher receiver to receiver detection performance than the 180 kHz, but both systems had sufficient detection performance to enable time syncing without issue. The tag to receiver detection performance was also higher for the 307 kHz system, but the 180 kHz system detected the sentinel tag at least 73% as often as the 307 kHz system for three of four receivers. The worst performing 180 kHz receiver detected the sentinel tag 59.2% as frequently as the 307 kHz receiver did from the same mooring.

While a bug in the downloading software prevented the retrieval of the 307 kHz noise file, the noise on the 180 kHz system was low when submerged, under reservoir conditions with gate openings near equalization. Data also showed reflections of signals is occurring, likely off the water surface. A reduction in the power of the sync tag transmission within each receiver may help mitigate this, although it isn't a huge issue.

Confirmation of correct positioning was not possible with the tag towed by boat as the handheld GPS frequency was intermittent and the positioning times could not be matched to the tag ping/detection.

4) Is the data obtained sufficient to justify including an acoustic program in the monitoring

Overall, both systems performed well and Innovasea is confident that either would easily provide a reliable assessment of the presence/absence of tags in the immediate area. Innovasea is also confident that the 307 kHz system can provide positioning results at the causeway and that the 180 kHz will provide positioning as well, especially after some minor tuning. As such, a program is justified and will help enable an understanding of fish behaviour at the structure and address if and when passage is being attempted and the number of passage attempts made through the structure by representative species (American eel, Atlantic salmon, Atlantic tomcod and gaspereau).

5.3 Discussion

5.3.1 Damage

Damage assessments have occurred throughout the year under natural river state (2022) but have only occurred for part of the year under a reservoir (June 2023 to January 2024). Natural river state existed on the Avon until June 2023 meaning the smelt and part of the gaspereau migration occurred under natural river state in 2023. Damage was observed to be lowest under natural river state in 2021 although significant temporal data gaps exist. An overall increase in damage was observed in 2022 under natural river state although water levels upstream of the causeway were observed to be lower that year suggesting a decreased allowance of tide upstream. Damage was observed to be highest during 2023 when a reservoir was maintained and gates were opened for a short period near when water levels upstream and downstream of the causeway were equal. Damage observed on the Kennetcook River increased slightly from 2022 to 2023 (from 11.71% to 13.58%), although this increase on the control river is not sufficient to fully explain the much larger increase in damage observed upstream of the causeway. This suggests that the change in gate operations from natural river state to maintaining a reservoir is likely attributed to much of the observed increase in overall fish damage upstream of the causeway in 2023.

Especially given that part of the gaspereau migration occurred under natural river state in 2020 and 2023, fish damage assessments suggest that gaspereau are most damaged under reservoir conditions with gate openings occurring near water level equalization, and least damaged under natural river state. Given that monitoring did not occur for the 2020 Atlantic tomcod migration and that natural river state occurred during increased Atlantic tomcod abundances in April 2023, the fact that damage was observed to be highest upstream of the causeway in 2023 followed by 2020 strongly suggests that gate operations that maintain a reservoir with openings occurring near equalization cause notably more damage to Atlantic tomcod than conditions under natural river state. This is especially convincing given that the increase in damage observed between 2022 to 2023 on the control site (Kennetcook River) is far outweighed by the increase observed upstream of the causeway. However, it is unclear why a similar increase in the percentage of damaged Atlantic tomcod was not observed downstream of the causeway in 2023. As so few observations of damaged striped bass occurred, general trends are difficult to discern with large fluctuations in percent damaged year to year. Due to significant temporal gaps in monitoring in 2020, it is not possible to assess if reservoir conditions in 2020 are associated with a similarly high level of damage to American eel as was observed in 2023 at the Avon causeway. Comparing damage to American eel on the Kennetcook River between 2022 and 2023 shows a small increase in damage, although this increase at the control site is not large enough to explain the considerable increase in damage observed at the causeway. This suggests that the change in gate operations from natural river state to maintaining a reservoir and opening gates near equalization contributes to a notable increase in damage to American eel.

5.3.2 Delays in Fish Passage

In a natural river setting, it would be expected to intercept similar amounts of migrating or residing fish at sites that are near each other (within a kilometer for example). As such, if fish are passing efficiently through a structure, then a similar CPUE should be observed on either side of the barrier assuming comparable methods are followed at each site. A larger mean CPUE observed downstream of the structure would suggest a buildup of fish is occurring representing a delay in passage and that passage is inefficient.

The difference in mean CPUE of gaspereau between upstream and downstream of the causeway is highest (least efficient) in years when natural river state is inconsistently provided, likely due to a lack of a sufficient ecological maintenance flow needed to attract fish upstream and keep them alive through the low tide period. Strong downstream flows (head pressure) that occur when water is released to control levels in the reservoir are also a contributing factor to poor passage efficiency under reservoir conditions. This difference in mean CPUE decreases (becomes more efficient) as gate openings become more consistent so as no water is impounded upstream of the causeway and a sufficient ecological maintenance flow is provided. Under natural river state, the head pressure caused by impounding water upstream of the causeway is removed resulting in greatly reduced water velocities that fish can better navigate against. Mean CPUE is observed to be higher upstream of the causeway during natural river state with intentional saltwater entry, meaning a buildup of gaspereau seeking upstream passage at the causeway is minimal and passage is considered efficient. This increased passage efficiency is clearly a result of the natural upstream push and guidance provided by allowing tidal flow upstream through the causeway. Further, given that fishing surveys occurred near or after high tide upstream of the causeway when gates were closed, the higher mean CPUE observed upstream of the causeway in 2021 and 2022 may have been a result of so many gaspereau in the upstream system that post-spawn gaspereau seeking downstream passage may have been building up waiting for gates to open.

Although abundances of rainbow smelt are low, it appears natural river state with intentional saltwater entry may be required to facilitate passage. Observations of young of the year smelt only downstream of the causeway suggest that passage is inefficient and ineffective for especially juveniles and/or that spawning and rearing habitat is lacking upstream.

Passage efficiency of Atlantic tomcod has remained poor in all years of study, although passage improved under natural river state with intentional saltwater entry. It is clear that Atlantic tomcod do not pass without water being permitted to flow upstream through the causeway, although a lack of stable spawning habitat resulting from an inconsistent “head of tide” combined with strong downstream flows during the migration window are certainly contributing factors to the lower mean CPUE observed upstream of the causeway. As shown through the increase in mean CPUE of Atlantic tomcod from 2021 to 2022 upstream of the causeway, it is likely that consistent natural river state with intentional saltwater entry occurring over several years may be required to re-establish an equilibrium and develop suitable spawning and rearing habitat conditions upstream.

While sampling for eggs has not occurred on the Avon, the only known striped bass spawning river in the region is the Shubenacadie and Stewiacke Rivers. As such, striped bass are generally in this system to feed and so given the strong swimming ability of striped bass, passage through the causeway is most likely a reflection of prey availability and density. This is clearly demonstrated by the similar trends in mean CPUE between striped bass and gaspereau. As such, natural river state with intentional saltwater entry better enables this ecosystem (which was historically an estuary) to function naturally. However, when passage for prey species such as gaspereau is inefficient and unnatural buildups of fish occur due to delays in passage, rates of predation can become unnatural and unbalanced resulting in a reduction to the productivity of the fisheries.

Given that American eel likely reside both upstream and downstream of the causeway, all individuals may not necessarily be seeking passage and so a similar mean CPUE observed upstream and downstream of the causeway is not necessarily indicative of efficient passage for American eel. Given the long lifespan of eels, potentially a decade of data or more would be required to detect the effects of gate operations on eel passage using only CPUE and so tagging data in unison with CPUE is essential in assessing passage of American eel on shorter time scales.

5.3.3 Delays in Migration

Gaspereau appear to be determined to complete their lifecycles and as the vast majority do not tend to deviate from their natal river, they tend to seek upstream passage until they achieve passage or often die trying. Although the run time figures show all life stages of a given species, in 2019 under reservoir conditions, gaspereau larger than 20cm in total length were observed at the causeway much longer than any other year of study (well into late July), and given that only seven gaspereau were caught upstream of the causeway that spring prior to May 22, 2019, suitable passage conditions were clearly not provided at the causeway in 2019. When large buildups of gaspereau occur and the run time of gaspereau is expanded considerably, there is a prolonged period over which an unnaturally large grouping of fish becomes susceptible to unnatural rates of predation or other mortality. Further, if the migration is delayed then spawning may also be delayed meaning the spawn may not properly align within the patterns of the natural system. This may result in a reduced hatch success rate and a hatch timing misaligned with that of their prey leading to unnatural mortality rates and a reduced productivity of this fishery. The peak gaspereau migration ended near late June in all other years, although the catch window in 2023 was extended due to the catch of young of the year gaspereau using a beach seine. The larger and more prolonged catches of young of the year gaspereau upstream of the Avon River compared to other sites in 2023 suggest that the closure of the gates also resulted in a buildup (delay in migration and inefficient passage) of young of the year gaspereau seeking downstream passage. The gaspereau from the Avon were delayed in their out migration, and likely faced disadvantage from a lack of protection in numbers, among many other unknown consequences leading to potentially unnaturally high rates of predation or other mortality and loss in productivity to the fishery. As such, closure of the gates and reservoir conditions causing a lack of passage lead to the prevention of fish from fulling their life processes, which has an impact on the habitat itself. For example, the migration of alewife represents a massive nutrient transfer that rivals that of Pacific salmon runs (Nau 2018), and several species of fish including alewife and blueback herring are known to be relied on by species of freshwater mussel to host their larvae stage in their gills (Martel, et al 2010).

Although there was historically a major rainbow smelt run on the Avon River prior to construction of the Avon causeway (Isaacman 2005), rainbow smelt are now only present in very low abundance making it difficult to determine a difference in run time between years. The run time should also consider the spring and fall run time separately in future analysis. While notable data gaps exist in most years of study prior to 2022, Atlantic tomcod run time is shorter under natural river state and intentional saltwater entry in 2022 compared to reservoir conditions in 2023. However, limited evidence is available to suggest large scale successful spawning is occurring upstream of the Avon causeway. Given that gate operations control the volume and mixing of waters upstream of the causeway, they certainly have an impact on temperature that can cause changes to the catch window of American eel. Sudden changes between prolonged gate operations (i.e. from natural river state to reservoir and vice versa) is also observed to cause a disruption in eel catches further suggesting that consistent gate operations improve the stability of the ecosystem.

Drivers behind the differences in run time are more difficult to decern for striped bass given its status as a predator species. Run time is most likely influenced by prey availability and water temperature, but with data gaps present for especially water temperature in earlier years of study, it is difficult to assess specific trends. However, providing as close to natural river conditions as possible would result in more natural patterns of water temperature and prey availability leading to more natural patterns of striped bass.

5.3.4 Acoustic Tagging

The detection window is limited to when receivers are submerged. The NSDA water level logger is situated at a higher elevation than the lower elevation receivers and so it is unclear when these receivers are actually exposed and cannot detect tags. As such, exposure windows for the lower elevation receivers are an estimate and will need to be further verified visually or with the use of a water level logger at each mooring point to determine the exact timing of the detection window.

The receiver-to-receiver detection serves only to time sync receivers to allow analysis of time on a very fine scale. Provided that receivers can communicate with each other frequently enough to regularly time sync, then the difference in performance is not relevant. Innovasea expressed that both systems had an excellent detection performance.

Although the 180 kHz system did not detect the sentinel tag as well as the 307 kHz system, the detection performance was still satisfactory as expressed by Innovasea, and could likely be improved with some minor tuning.

Overall, both systems performed well and Innovasea is confident that either would easily provide a reliable assessment of the presence/absence of tags in the immediate area. Innovasea is also confident that the 307 kHz system can provide positioning results at the causeway and that the 180 kHz will provide positioning as well, especially after some minor tuning. Given that both systems perform well, there is a clear advantage in using the 180 kHz system as this is the only system where pressure tags are available to provide a depth position, and there are also numerous tagged fish and receivers utilizing the 180 kHz system that have already been deployed. The existing receiver infrastructure and tag deployments can be used to compliment and expand the knowledge gained through acoustic tagging and receiver deployments at the causeway.

5.4 Gaps and Lessons Learned

Frequent changes in staffing from Acadia University and the CMM resulted in several changes in who was assessing damage. While attempts were made to train and standardize damage assessments, different people may have categorized damage differently (abrasion assessed as wound or vice versa for example), and some damage may have inadvertently not been recorded. However, it is unlikely that an undamaged fish was incorrectly assessed as having damage.

Analysis of runtime currently includes all life stages of a given species over the year and so it is difficult to quickly decern if a particular migration was delayed for species such as gaspereau where current analysis includes the adult spawning migration, the out migration of young of the year and the catch of juveniles feeding in estuaries over the summer and fall. A runtime based on size class would be more appropriate moving forward.

Consistent monitoring through as much of the year as possible is essential for assessing differences in fish passage caused by different gate operations. Data gaps cause severe limitations to analysis and interpretations of differences in mean CPUE and run time. Beginning monitoring as early in April as possible helps to avoid missed fish migrations and minimizes data gaps. Establishing multi-year monitoring contracts would also help ensure equipment, staffing and plans are in place well in advance to avoid scrambling last minute to deploy gear, which runs a much higher risk of creating unnecessary data gaps.

Receiver moorings need to be stronger to withstand the extreme forces at the causeway.

The 180 kHz acoustic system can be tuned to reduce reflections and increase tag and receiver detectability at this location.

In future acoustic tests where a test tag is drifted with a boat, the handheld GPS needs to sample at least as frequently as the tag ping rate, on a fixed time interval and have Wide Area Augmentation System (WAAS) enabled.

6.0 Objective 4 - Evaluate Changes in Fish Habitat

6.1 Methods

6.1.1 Assess Suitability of and Changes in Water Characteristics

Water quality measurements including temperature, pH, salinity, and dissolved oxygen (DO) were made using a YSI ProPlus multiparameter meter during each fish monitoring survey. The YSI meter was calibrated prior to each sampling day (Table 14) and both a surface measurement and "at depth" measurement was taken at each sampling site on the Avon River (Figure 13) and Kennetcook River (Figure 14). "At depth" refers to either just above the bottom or a depth of 4.3m (14 feet; whichever is shallower). Measurements were taken at several sites upstream of the causeway to determine the approximate location of the saltwater wedge on each given survey. Downstream of the causeway, water quality measurements were taken near the 3" net and near the gated structure just after gear was set, approximately 2.5 hours prior to the posted high tide time for Hantsport (station 0082). On the Kennetcook River, water quality measurements were taken near the 3” net just after it was set, approximately 1.5 to 2 hours prior to the posted high tide time for Hantsport (station 0082).

HOBO loggers were deployed at several locations upstream of the Avon causeway and at one site on the Kennetcook River by CBCL to assess DO, temperature, conductivity and water level. Note that station 3 near Sangster Bridge was lost after reservoir conditions were established. In 2023, Envirosphere Consultants Limited analyzed water samples collected from just above the causeway to determine *E. coli* and total coliform counts. Test results were provided by Darren Porter and were conducted weekly from June 29 to October 6, 2023.

Beginning in October 2023, a secchi disc was used to assess turbidity at each site. A 20cm diameter secchi disc was lowered into the water column until the disc could no longer be seen, then lifted until observed again. The corresponding water depth was then recorded as the “secchi depth”, which will be useful in assessing any changes in water turbidity over time.

Table 14 YSI Calibration Solutions

Water Quality Variable	**Salinity**	**ORP**	**pH**		
			4	**7**	**10**
Calibration value at 25℃	12880 uS/cm	225 mV	4.00	7.00	10.00
Variation	+/- 50 uS/cm	+/- 5%	0.01	0.01	0.01
Manufacturer	HANNA instruments	Sensorex	Hoskin Scientific	Hoskin Scientific	Hoskin Scientific
Product Details	HI7030	Part No B225	A999-PHB04-4L	A999-PHB07-4L	A999-PHB10-4L

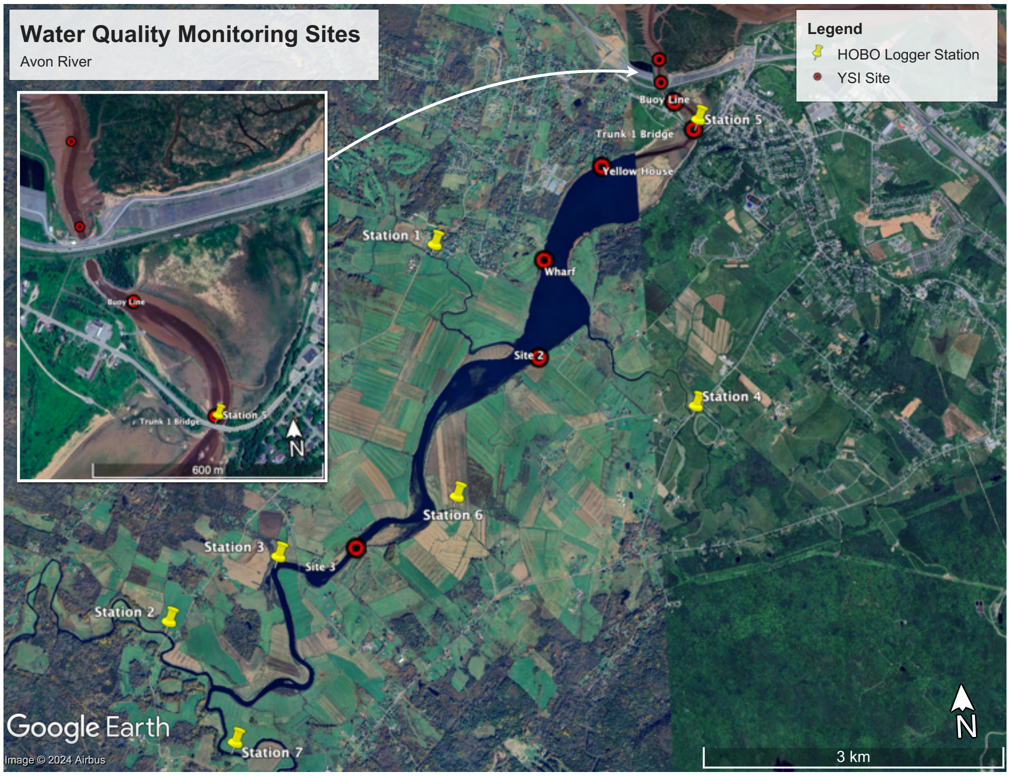

Figure 13 Water Quality Monitoring Sites Avon River

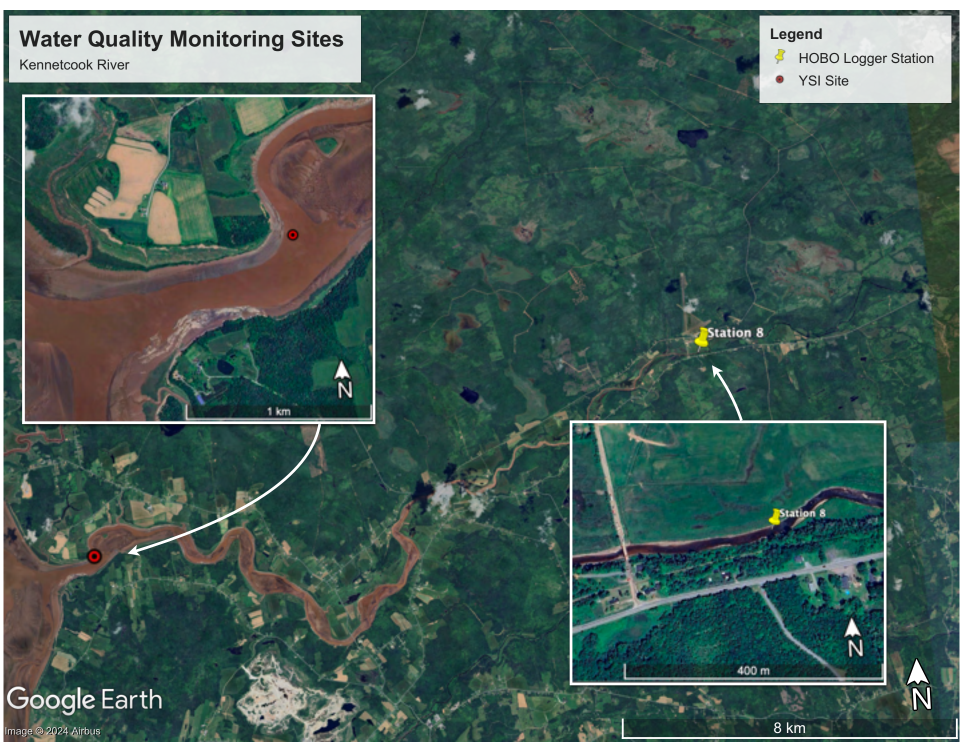

Figure 14 Water Quality Monitoring Sites Kennetcook River

6.1.2 Assess Suitability of and Changes in Fish Habitat

6.1.2.1 HSI

HSI surveys were conducted upstream of the Avon causeway (Figure 15) and on the Kennetcook River (Figure 16) following the Nova Scotia Fish Habitat Assessment Protocol, developed by Adopt A Stream. This protocol is a standardized freshwater fish habitat assessment that utilizes habitat suitability variables and values specific to Nova Scotian rivers. Surveys include an assessment of water quality, channel cross-sections, embeddedness, substrate and cover, riverbanks and riparian areas, and benthic macroinvertebrates. Adopt A Stream's HSI analysis tool uses habitat variables assessed in the field to produce an accurate assessment of the quality of fish habitat, represented by the physical and basic water quality conditions of specific stretches of river. Details on how surveys are conducted can be found here: http://adoptastream.ca/sites/default/files/The%20Nova%20Scotia%20Fish%20Habitat%20Assessment%20Protocol-%20June%202018.pdf.

The intention of these surveys is to assess if changes are occurring to fish habitat over time. With the understanding that CB Wetlands and Environmental Specialists have carried out assessments of the habitat between the Avon causeway and Sangster Bridge (Kickbush et al. 2022), HSI surveys were carried out at locations upstream of that area, utilizing sections of streams that were easily accessible and also representative of the stream overall. Changes in habitat quality may lead to a change in the abundance of a given fish species over time. Establishing a temporal record of habitat characteristics at these sites will be useful in assessing the cause of potential changes in fish abundance in the future. For example, if no change in these habitats are observed, then changes in abundance may be more directly related to other factors including changes in gate operation.

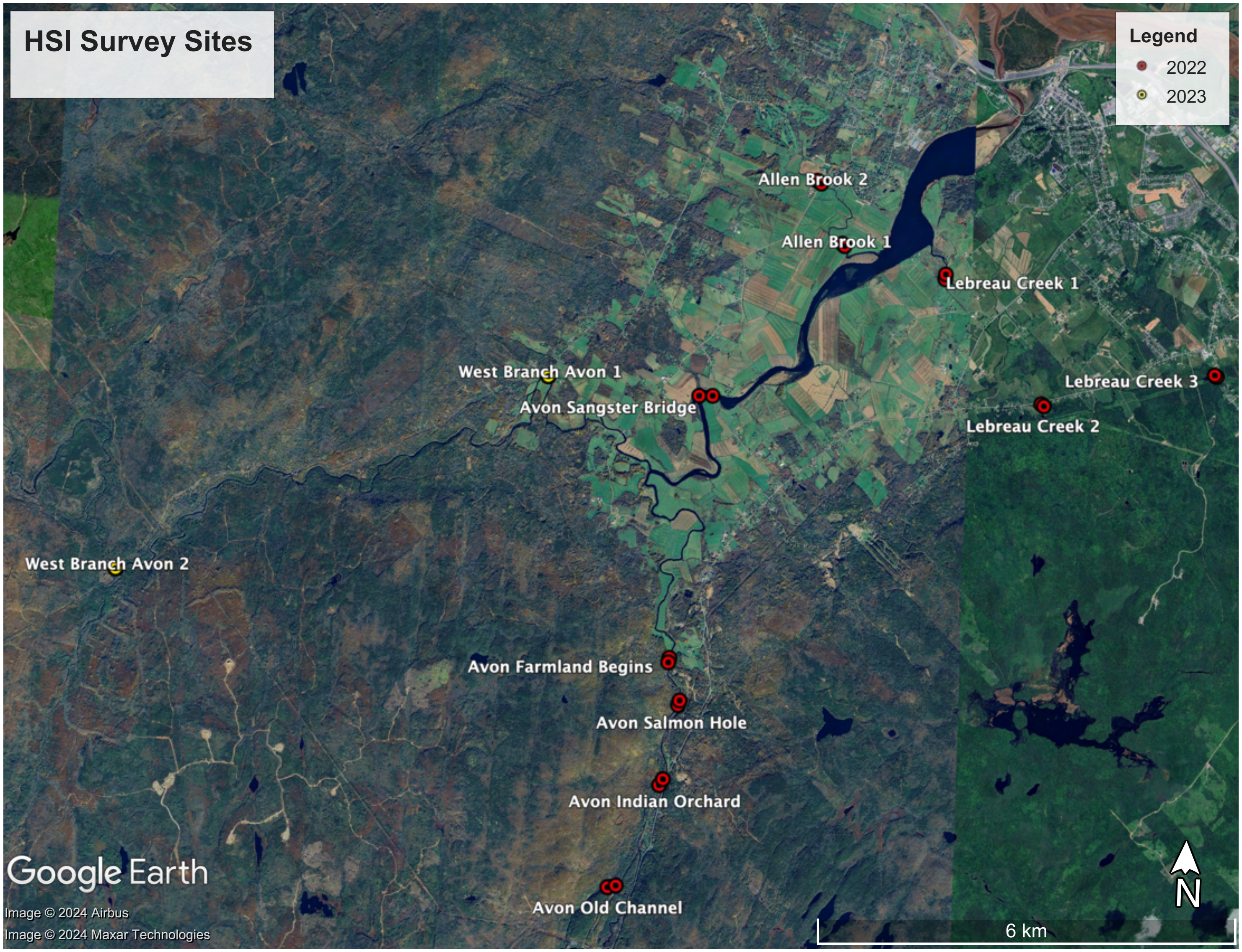

Figure 15 HSI survey sites on the Avon River.

Figure 16 HSI survey sites on the Kennetcook River.

6.1.2.2 Bird Abundance and Diversity

The state of fish habitat can also be assessed in proxy by observing differences and changes in bird assemblages and abundances. As such, beginning October 3, 2023, counts of birds were recorded by species (or grouped into categories if identification to species was not possible) while deploying gear at each site. General bird categories included "ducks", "geese", "gulls" and "shorebirds". Given that gear is consistently deployed at the same locations at each monitoring site, a general "observation area" was defined and used to determine a count of birds per square kilometer (Figure 17). This allows observations to be standardized and compared between sites.

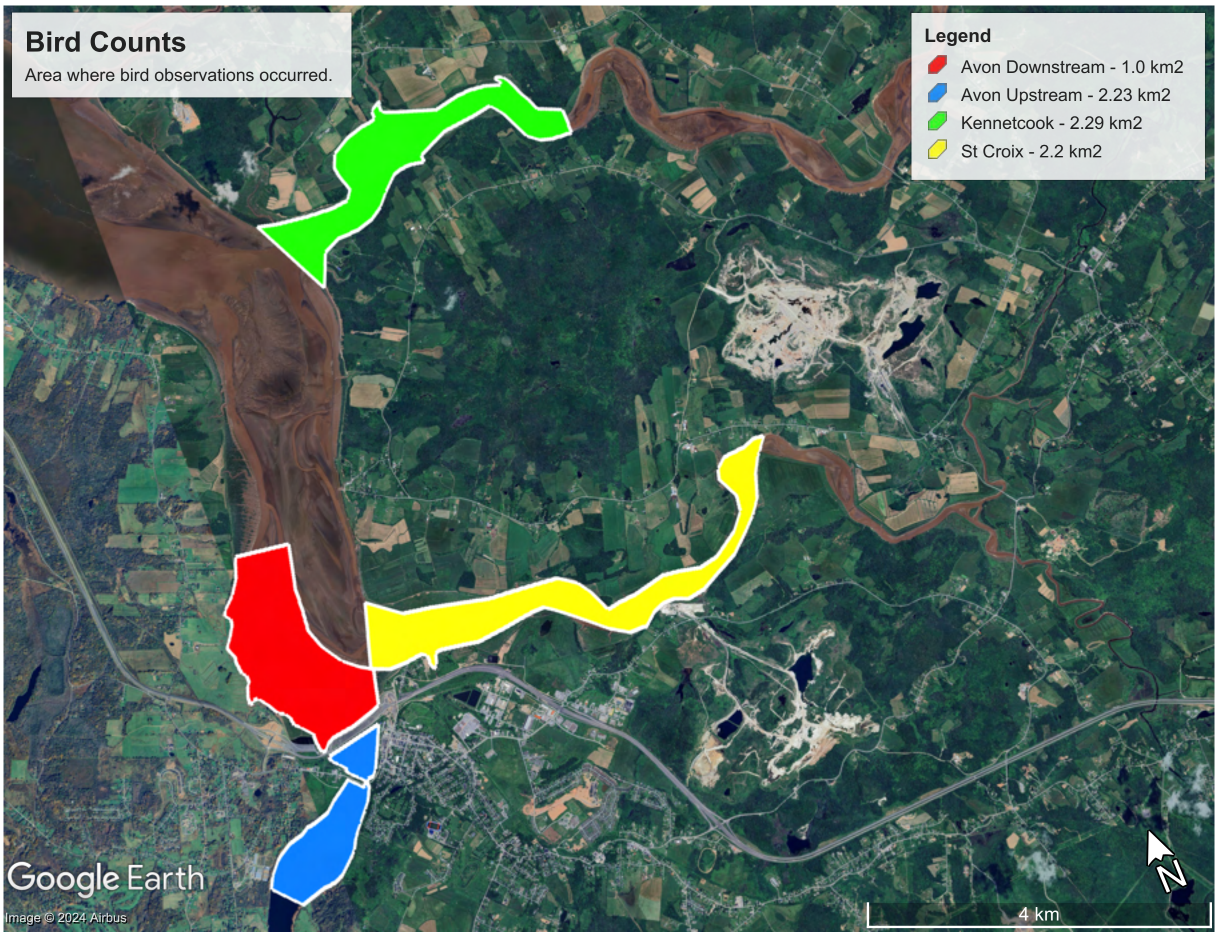

Figure 17 Defined observation areas for bird counts.

6.2 Results

6.2.1 Water Characteristics

Figures outlining various water quality parameters are located in Appendix H - Water Quality for both YSI and HOBO logger observations. Vertical dashed lines indicate known dates for significant events and/or changes in gate operations. The first line indicates when DFO mandated that the NSDA drop the reservoir and maintain natural river like conditions (May 14, 2020), the second indicates when the reservoir levels were raised and maintained at 3-4 feet (May 28, 2020) and the third indicates when the reservoir levels were further raised and maintained at 9 feet (June 9, 2020). The fourth vertical line indicates when the current ministerial order was issued (March 18, 2021), and the reservoir was returned to natural river state. The fifth vertical line indicates when the state of emergency was declared and reservoir conditions were established upstream of the causeway (June 1, 2023). Shallow measurements were taken at the surface while deep measurements were taken at a depth of up to 4.3m (14 feet) or at the bottom of the water column, whichever was shallower. Measurements presented for "upstream" represent the average of all measurements taken upstream of the causeway on a particular date.

Temperature

Based on YSI measurements, water temperature is considerably warmer on the Avon compared to the Kennetcook River, with a maximum temperature of 26.3°C observed upstream of the causeway, 26°C downstream and 21.5°C observed on the Kennetcook River (Table 15). Temperature trends were comparably smooth downstream of the causeway and on the Kennetcook River but more variable upstream of the causeway, which also experienced the most extreme ranges in temperature. Temperatures at all sites increased through the summer and decreased through the fall and early winter, although a notable spike in temperature of approximately 5°C or more occurred in December 2023 at all sites. Also of interest is that water HOBO loggers recorded a water temperature decrease of approximately 5°C at all sites, including on the Kennetcook River in early June.

Table 15 Temperature min, max and mean in degrees Celsius for each site and year based on YSI measurements.

Year	Avon Upstream			Avon Downstream			Kennetcook River		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
2020	0.70	27.50	17.20	3.30	21.90	9.70	-	-	-
2021	-0.30	26.60	9.77	0.80	25.20	12.87	-	-	-
2022	0.00	26.90	12.43	-0.20	25.00	13.09	1.80	23.00	13.41
2023	0.60	26.30	11.86	0.70	26.00	11.61	1.40	21.50	10.86

Salinity

Salinity levels fluctuated considerably upstream and downstream of the causeway, mostly in relation to gate operations (Table 16). Even under natural river state, salinity levels upstream were dependant on the time period over which gates were opened (determine the amount of tide let upstream) and the volume of freshwater runoff flowing downstream. In 2023, the reservoir was largely freshwater although a slightly brackish period did occur in October through December with salinities reaching as high as 2.13 at the Ski Martock Pumphouse (over 6km upstream of the causeway) on October 16, 2023. HOBO logger data also confirms fluctuations in conductivity upstream of the causeway with values recorded higher than 30,000 uS/cm on two occasions. However, YSI salinity measurements show salinity highest after October in 2023 upstream of the causeway (trunk 1 bridge) and HOBO conductivity measurements show conductivity highest until July. Perhaps most important is the sudden change in salinity pattern observed downstream of the causeway after reservoir conditions occurred in 2023. When a reservoir is maintained and freshwater is released downstream (or during considerable freshwater runoff events under natural river state), the force of the freshwater flow pushes the estuarine salt wedge further downstream. As such, a much stronger freshwater signal is often observed downstream of the causeway under those circumstances, and as far as approximately one kilometer downstream of the causeway. Such a strong freshwater signal during an incoming or high tide is not common for estuarine environment, as demonstrated when comparing salinity observations between the Avon and Kennetcook Rivers. On the Kennetcook River, salinity measurements rarely dropped below 10 during incoming or high tide. Note that water quality measurements were also taken during beach seining that occurred while the tide was out. This resulted in several freshwater signals being recorded, which explain the freshwater signal at depth in 2023, as shown in the salinity figures in Appendix H - Water Quality.

Table 16 Salinity min, max and mean in psu for each site and year based on YSI measurements.

Year	Avon Upstream			Avon Downstream			Kennetcook River		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
2020	0.01	16.58	3.49	0.06	20.98	7.19	-	-	-
2021	0.01	25.13	4.35	0.04	25.96	14.94	-	-	-
2022	0.04	26.99	4.12	0.04	29.13	14.25	15.97	34.30	24.54
2023	0.02	17.61	2.14	0.04	24.02	6.33	7.63	27.34	20.07

DO

The lowest recorded measurement of DO using a YSI was 3.25 mg/L, which was observed upstream of the causeway in July 2020 under reservoir conditions (Table 17). The next lowest was 3.74 mg/L also recorded upstream of the causeway under reservoir conditions in June 2023. The lowest observed DO measurement in 2021 and 2022 were notably higher, with the highest occurring in 2021 when natural river state occurred, and higher levels of tide were being permitted upstream. HOBO logger deployments experienced issues with DO sensor caps and some issues with burial by sediments. As such, prolonged periods of near zero measurements may be a result of sensor complications. Overall, HOBO loggers recorded high fluctuations in DO at all sites (which as described by complications experienced, may not necessarily reflect the ecosystem) and show a similar trend where DO is lowest in summer and higher in cooler, wetter seasons. The Canadian water quality guidelines for the lowest acceptable DO concentrations is 5.5 mg/L for older life stages in warm-water ecosystems, and 6.5 mg/L for older life stages in cold-water ecosystems (CCME, 1999). DO observations failed to meet the warm water guideline only on the Avon River (Table 18). The guideline was not met downstream of the causeway five times in 2022 and three times in 2023 while upstream of the causeway the guideline was not met on 12 occasions in 2020, 0 in 2021, 5 in 2022 and 17 in 2023. As such, DO levels improve under natural river state, especially with increased tidal flow and become depleted much more frequently under reservoir conditions.

As DO measurements have only been collected after mid tide in previous years, a significant data gap exists particularly downstream of the causeway at low tide. If gates are closed on the outgoing tide, the only water available downstream of the causeway to maintain characteristics sufficient for the conservation and protection of the fish and fish habitat is what leaks through the gate sills or what comes through small holes drilled in the gates to prevent sediment buildup on the gates. While few measurements have been collected during this time downstream, DO levels were observed to decrease at a rate of 0.52mg/L per hour on June 2, 2023 while gates were closed near the low tide period (DO dropped from 6.23 mg/L at 07:34h to 5.84 mg/L at 8:19h). Further, fish have been observed gasping for oxygen on several occasions when gates were closed during the low tide period. As such, without sufficient downstream flows, it is highly likely that negative impacts are occurring to the fish and fish habitat while gates are closed during the low tide period.

Table 17 DO minimum and mean in mg/L for each site and year based on YSI measurements.

Year	Avon Upstream		Avon Downstream		Kennetcook River	
	Min	Mean	Min	Mean	Min	Mean
2020	3.25	9.36	6.37	11.42	-	-
2021	5.80	12.51	5.70	10.87	-	-
2022	4.51	11.19	4.59	9.83	6.23	9.76
2023	3.74	10.95	5.20	11.06	6.32	10.66

Table 18 Occurrences when DO concentrations were observed to be below recommended minimums.

Year	Avon Upstream	Avon Downstream	Kennetcook River
2020	12	0	-
2021	0	0	-
2022	5	5	0
2023	17	3	0

pH

Measurements of pH are much more stable under natural river state and tidal flow conditions compared to when a reservoir is maintained. Observations of pH in the 7.5 to 8 range are indicative of a strong estuarine signal whereas observed drops in pH are associated with a more freshwater signal. Of particular note is the sudden change in pH from a fairly stable 7.5-8 on the incoming tide to a highly variable 6-8 range observed downstream of the causeway and slightly less variable pH from 6.5-8 upstream of the causeway after June 1, 2023 when gates were closed and a reservoir was maintained. Note that the two measurements of pH below 7 shown on figures of the Kennetcook were taken near head of tide (freshwater) compared to other measurements taken downstream within the estuary. Overall, pH measurements are indicative of a healthy estuarine system on the Kennetcook River while the Avon shows signs of instability and considerable freshwater influence (Table 19). Water quality guidelines for the protection of aquatic life provided through the Canadian Council of Ministers of the Environment (CCME, 1999) recommend pH remain from 7.0 to 8.7 in estuarine environments (unless it can be demonstrated that the observed pH is a result of natural processes). While measurements of pH were always observed within this recommended range on the Kennetcook River, measurements were above and below the recommended range at least once upstream of the causeway each year (
Table 20). Downstream of the causeway, measurements were recorded below this range each year, especially in 2023 while measurements never exceeded the recommended pH range downstream of the causeway.

Table 19 pH min, max and mean for each site and year based on YSI measurements.

Year	Avon Upstream			Avon Downstream			Kennetcook River		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
2020	5.91	9.34	7.54	6.99	8.36	7.63	-	-	-
2021	6.71	9.82	7.93	6.77	8.35	7.70	-	-	-
2022	6.85	9.68	7.73	6.87	8.70	7.72	7.41	8.10	7.78
2023	6.20	9.92	7.37	5.91	8.50	7.32	7.40	8.01	7.73

Table 20 Occurrences where pH did not meet recommended range.

Year	Avon Upstream	Avon Downstream	Kennetcook River
Occurrences where pH >8.7			
2020	2	0	-
2021	26	0	-
2022	10	0	0
2023	1	0	0
Occurrences where pH <7			
2020	2	1	-
2021	7	2	-
2022	4	4	0
2023	75	74	0

E. coli

Results of weekly water sampling carried out by Envirosphere Consultants Limited in summer and fall of 2023 were provided by Darren Porter and show fluctuations of *E. coli* levels upstream of the causeway (Figure 18). *E. coli* levels were observed to peak at 39000 CFU per 100mL on August 31, 2023, which is 97.5 times the Health Canada recreational water quality guideline. Water samples failed to pass the Health Canada guideline on two other occasions including August 10, 2023 (3100 CFU per 100mL) and September 21, 2023 (600 CFU per 100mL).

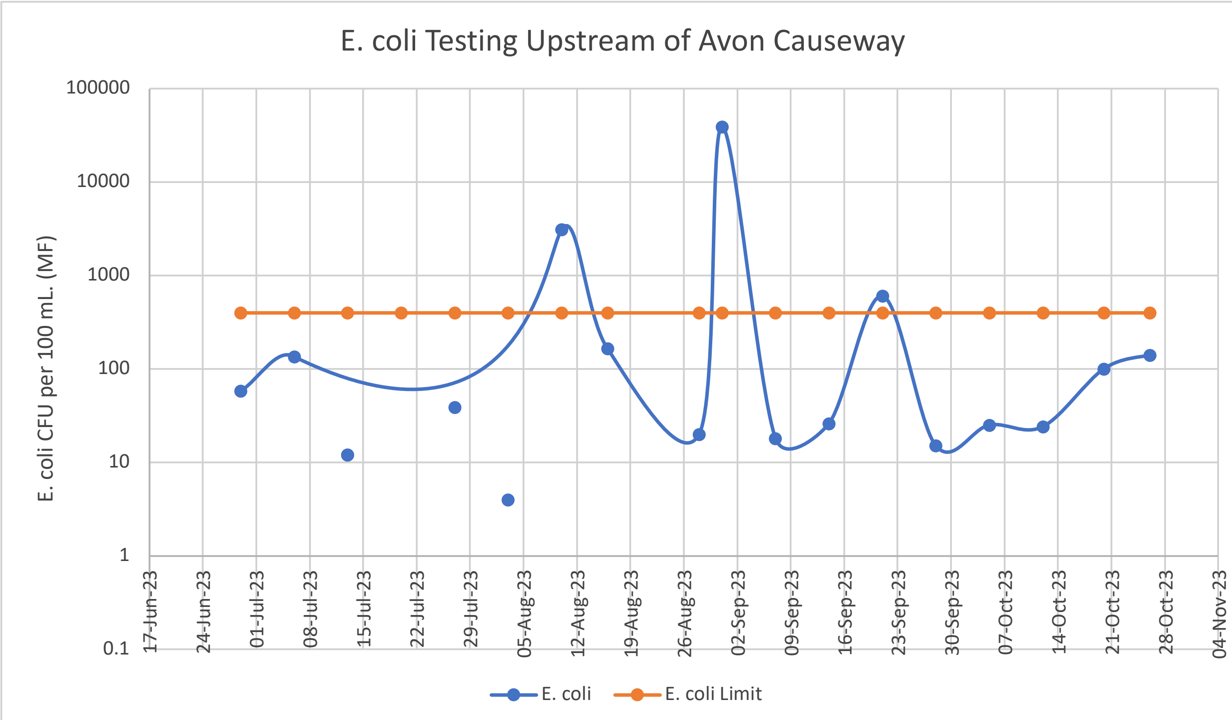

Figure 18 E. coli water test results of Avon River in 2023 near Trunk 1 Bridge, Falmouth.

6.2.2 Fish Habitat

6.2.2.1 HSI

HSI surveys were conducted at 12 sites upstream of the Avon causeway and at four sites on the Kennetcook to provide a baseline for future comparison. Using Adopt A Stream's HSI analysis tool, habitat characteristics at each site were assessed and tabled for brook trout (Table 21) and Atlantic salmon (Table 22). The analysis tool calculates 15 important criteria for each species in a range from 0-1, where poor quality is given a value of less than 0.4, moderate quality has a value from 0.4 to 0.8, and good quality has a value of greater than 0.8. For easier identification, the program gives poor quality variables a red color, medium quality a yellow color and good quality a green color.

Across all sites and both species, the percent of instream cover for fry was assessed as good and streambanks appeared well vegetated. However, most sites in the Avon watershed were assessed as having a low percentage of rooted vegetation or stable rocky ground cover and are considered vulnerable to erosion. In the Kennetcook watershed, only Little River was assessed as vulnerable for erosion. In areas most impacted by agricultural activities (Allen Brook and lower sections of the Avon and LeBreau Creek), stream shade was rated as poor while areas in more forested sections (upper Avon, upper LeBreau Creek and most of the Kennetcook sites were rated as moderate to good. The dominant substrate type in riffle-run areas was rated as moderate to good at all sites except for lower on Allen Brook, Avon Old Channel and LeBreau Creek 2, which were each rated as poor.

The majority of sites in both watersheds were rated as having good pH for both species although the West Branch Avon River had moderate pH for both species, the Sangster Bridge site had moderate pH for salmon (good for brook trout) and Tomcod River in the Kennetcook watershed had poor pH for both species. Water temperatures were rated as moderate to good for both watersheds when considering salmon, although two sites downstream on LeBreau Creek were assessed as poor for brook trout.

Although the percent of habitat available as pools were assessed as moderate to good for brook trout on the main Avon branch, lower section of LeBreau Creek and on O'Toole Brook in the Kennetcook watershed, only some portions of the main Avon and on O'Toole Brook were found suitable for salmon and none of these pools had a good class rating. Overall, there is a general lack of good pool habitat identified in both watersheds and for both species.

The instream availability of cover for parr is also limited at most sites with only the upstream site on the West Branch Avon River having good parr cover. The next best site assessed in the Avon watershed was the Avon Old Channel (adjacent channel to the Avon 1 powerhouse) with the remainder rated as poor. All sites in the Kennetcook watershed were rated moderate for instream parr cover.

Table 21 HSI Baseline for brook trout in the Avon and Kennetcook Watersheds (2022-2023)

Site Name	Date Surveyed	% Pools	Pool Class Rating	% Instream Cover (fry)	% Instream Cover (parr)	Dominant Substrate Type in Riffle-Run Areas	Average Percent Vegetation Along the Streambank	Avg % Rooted Vegetation and Stable Rocky Ground Cover	Average Maximum Water Temperature	pH	Percent Fines in Riffle-Run Areas	Percent Substrate Size Class for Winter Escape	Avg Thalweg Depth During Late Growing Season	% Stream Shade
Allen Brook 1	2022-12-18	0.30	0.30	1.00	0.21	0.30	1.00	1.00	0.42	1.00	0.00	0.03	0.83	0.30
Allen Brook 2	2022-12-18	0.30	0.30	1.00	0.33	0.60	1.00	0.20	0.42	1.00	0.36	1.00	0.08	0.30
Avon Farmland Begins	2022-09-16	0.52	0.60	1.00	0.34	1.00	1.00	0.69	1.00	1.00	1.00	1.00	0.68	0.37
Avon Indian Orchard	2022-09-16	1.00	0.60	0.88	0.27	1.00	1.00	0.73	0.98	1.00	1.00	1.00	0.54	0.93
Avon Old Channel	2022-09-12	0.94	0.30	1.00	0.44	0.30	1.00	0.25	0.44	1.00	0.24	1.00	0.99	1.00
Avon Salmon Hole	2022-09-12	1.00	0.60	1.00	0.26	1.00	1.00	0.20	0.59	0.97	1.00	1.00	0.32	0.79
Avon Sangster Bridge	2022-11-05	0.46	0.60	1.00	0.34	0.60	1.00	1.00	1.00	0.96	1.00	1.00	0.98	0.30
Lebreau Creek 1	2022-12-18	0.85	0.60	1.00	0.30	0.60	1.00	0.36	0.40	0.98	0.30	1.00	0.78	0.30
Lebreau Creek 2	2022-12-18	0.30	0.30	1.00	0.19	0.30	1.00	0.25	0.40	1.00	0.00	0.33	0.83	0.72
Lebreau Creek 3	2022-06-06	0.30	0.30	1.00	0.17	1.00	1.00	0.33	1.00	1.00	1.00	1.00	0.40	0.93
West Branch Avon 2	2023-10-26	0.30	0.30	1.00	1.00	0.30	1.00	1.00	1.00	0.56	0.82		0.89	1.00
West Branch Avon 1	2023-10-26	0.30	0.30			0.60	1.00	0.20	1.00	0.65	0.98	1.00	0.13	0.30
Birch Brook	2023-10-16		0.60			1.00	1.00	0.97	1.00	1.00		1.00		0.86
Little River	2023-10-26	0.30	0.30	1.00	0.56	1.00	1.00	0.36	1.00	1.00	1.00	1.00	0.35	0.72
O'Toole Brook	2023-10-xx	0.70	0.60	1.00	0.79	1.00	1.00	1.00	1.00	1.00		1.00	0.60	1.00
Tomcod River	2023-10-23	0.30	0.30	1.00	0.61	0.60	1.00	1.00	1.00	0.09		1.00	0.41	0.37

Table 22 HSI Baseline for Atlantic salmon in the Avon and Kennetcook Watersheds (2022-2023)

Site Name	Date Surveyed	% Pools	Pool Class Rating	% Instream Cover (fry)	% Instream Cover (parr)	Dominant Substrate Type in Riffle-Run Areas	Avg % Vegetation Along the Streambank	Avg % Rooted Vegetation and Stable Rocky Ground Cover	Summer Rearing Temp During Growing Season	pH	Fry Water Depth	Parr Water Depth	% Stream Shade
Allen Brook 1	2022-12-18	0.12	0.30	1.00	0.21	0.30	1.00	1.00	1.00	1.00	0.90	1.00	0.30
Allen Brook 2	2022-12-18	0.12	0.30	1.00	0.33	0.60	1.00	0.20	1.00	1.00	0.10	0.10	0.30
Avon Farmland Begins	2022-09-16	0.52	0.60	1.00	0.34	1.00	1.00	0.69	1.00	1.00	1.00	1.00	0.37
Avon Indian Orchard	2022-09-16	0.66	0.60	0.88	0.27	1.00	1.00	0.73	1.00	1.00	1.00	1.00	0.93
Avon Old Channel	2022-09-12	0.94	0.30	1.00	0.44	0.30	1.00	0.25	0.42	1.00	1.00	1.00	1.00
Avon Salmon Hole	2022-09-12	0.32	0.60	1.00	0.26	1.00	1.00	0.20	0.55	1.00	1.00	1.00	0.79
Avon Sangster Bridge	2022-11-05	0.40	0.60	1.00	0.34	0.60	1.00	1.00	0.74	0.75	0.88	1.00	0.30
Lebreau Creek 1	2022-12-18	0.12	0.30	1.00	0.33	0.60	1.00	0.20	1.00	1.00	0.10	0.10	0.30
Lebreau Creek 2	2022-12-18	0.12	0.30	1.00	0.19	0.30	1.00	0.25	1.00	0.91	0.28	0.32	0.72
Lebreau Creek 3	2022-06-06	0.12	0.30	1.00	0.17	1.00	1.00	0.33	0.96	0.98	1.00	1.00	0.93
West Branch Avon 2	2023-10-26	0.12	0.30	1.00	1.00	0.30	1.00	1.00	0.66	0.53	1.00	1.00	1.00
West Branch Avon 1	2023-10-26	0.12	0.30			0.60	1.00	0.20	0.77	0.68	0.09	0.09	0.30
Birch Brook	2023-10-16		0.60			1.00	1.00	0.97	0.80	0.86			0.86
Little River	2023-10-26	0.12	0.30	1.00	0.56	1.00	1.00	0.36	0.90	1.00	0.86	1.00	0.72
O'Toole Brook	2023-10-xx	0.85	0.60	1.00	0.79	1.00	1.00	1.00	0.77	1.00	1.00	1.00	1.00
Tomcod River	2023-10-23	0.12	0.30	1.00	0.61	0.60	1.00	1.00	0.66	0.00	0.02	0.02	0.37

6.2.2.2 Bird Abundance and Diversity

Beginning on October 3, 2023, records of bird diversity and abundance were regularly logged when conducting fish surveys. Upstream of the causeway there were four species or groups observed including duck, eagle, geese but predominantly gull. Downstream of the causeway there were 11 species or groups including cormorant, duck, eagle, geese, gull, heron, merganser, shorebird, snow goose, teal and wood duck. On the Kennetcook River there were nine species or groups including duck, eagle, geese, gull, heron, merganser, osprey, red tailed hawk and snow goose.

Overall, bird abundance per km^2 was observed to be highest downstream of the Avon causeway (Figure 19), second highest on the Kennetcook River and lowest upstream of the causeway (Figure 20). Duck were most commonly observed followed by geese and gulls. On average, 227 duck were observed downstream of the causeway per km^2, 186 on the Kennetcook and less than one upstream of the causeway each survey. For geese, 128 per km^2 were observed downstream of the causeway, 186 on the Kennetcook and less than one upstream of the causeway per survey. The maximum abundance per km^2 was observed to be 762 duck and 582 geese downstream of the causeway, 458 duck and 895 geese on the Kennetcook River and only 13 duck and 3 geese upstream of the causeway.

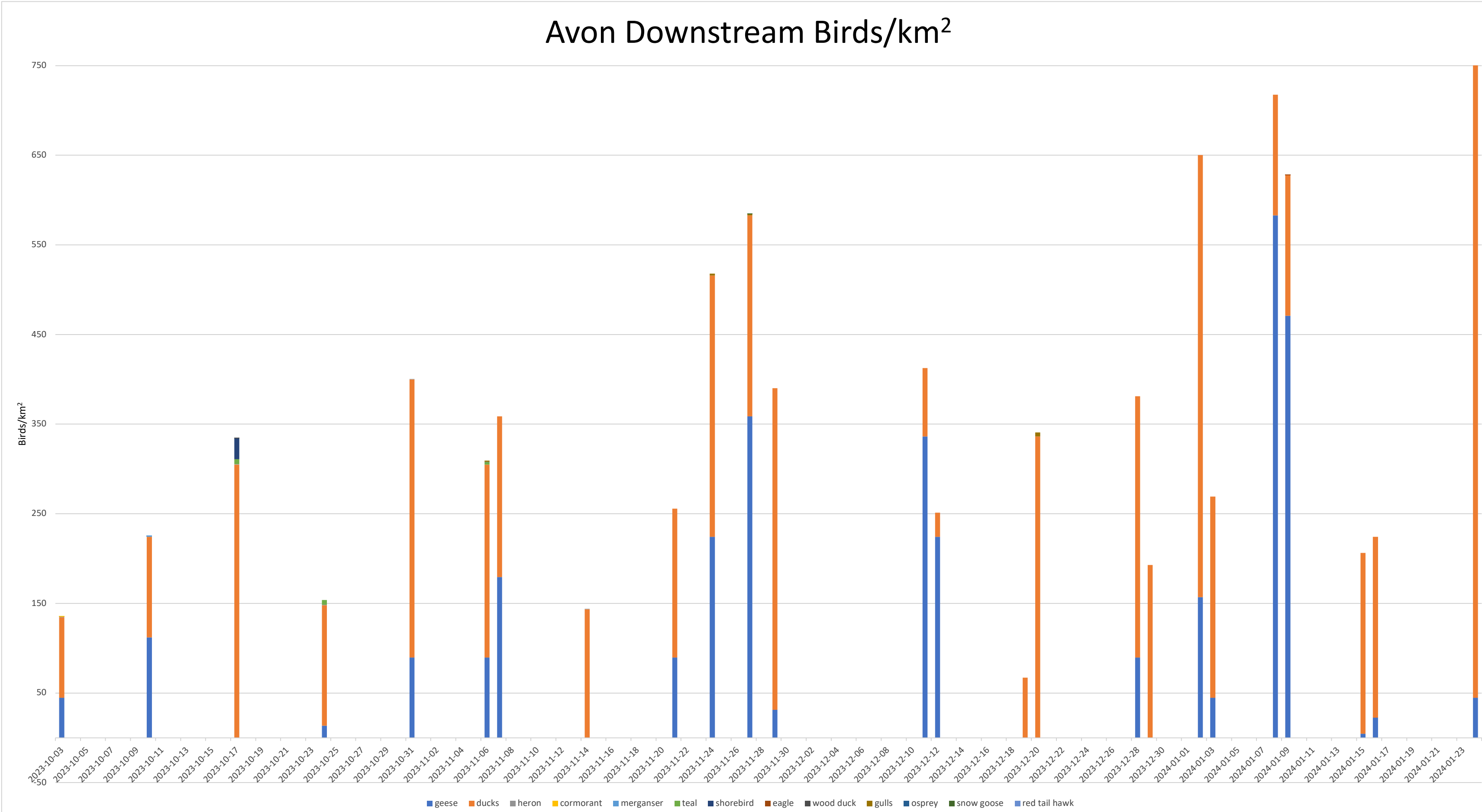

Figure 19 Bird Counts Downstream of Avon Causeway, 2023

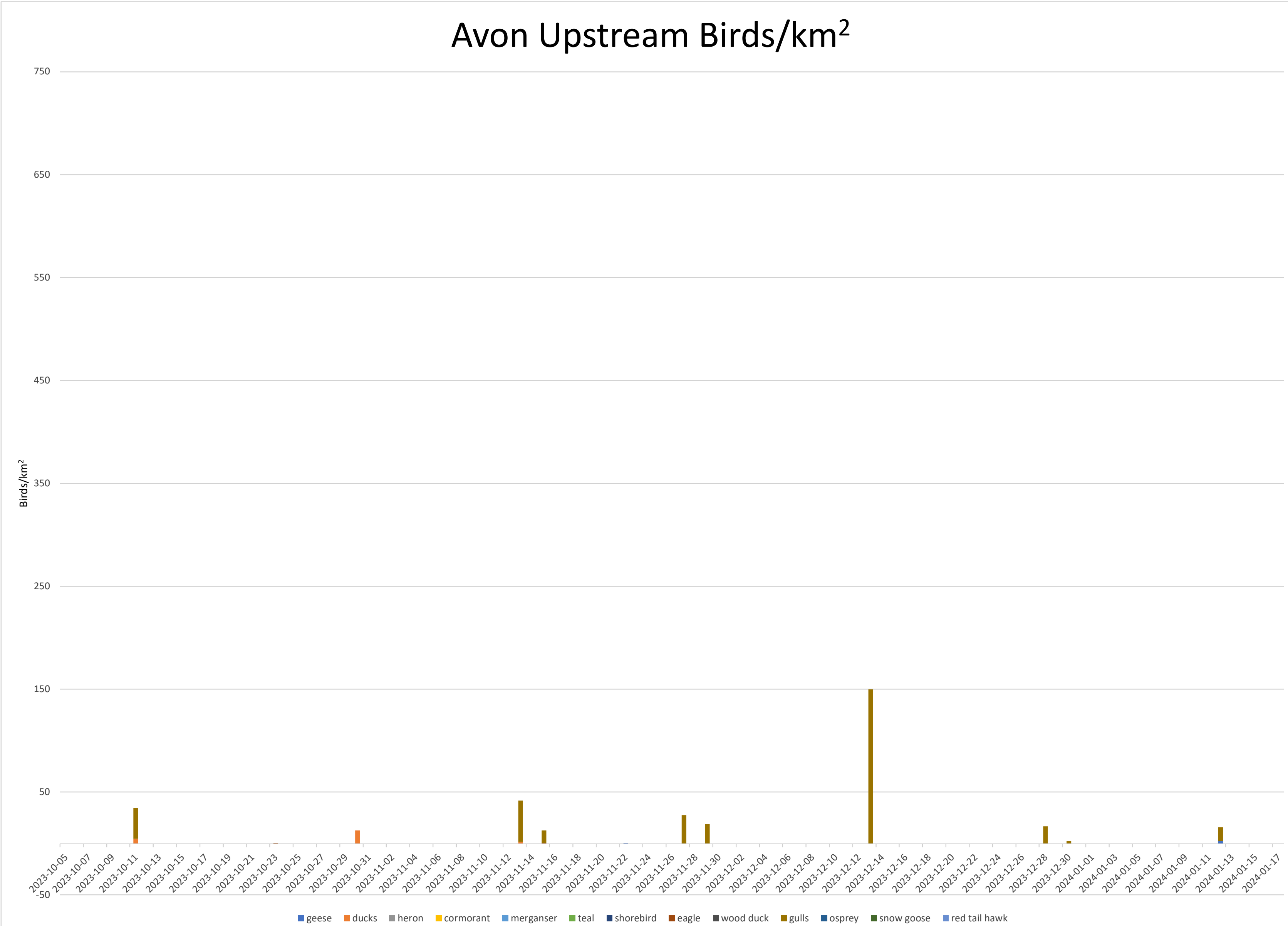

Figure 20 Bird Counts Upstream of Avon Causeway, 2023.

6.3 Discussion

Water quality

While HOBO logger data shows a clear decrease in temperature at all sites upstream of the Avon causeway in June, a similar decrease was also observed on the Kennetcook River suggesting this was a natural phenomenon and was not related to the establishing of reservoir conditions. The decrease in temperature was most likely related to a shift in weather patterns from the dry spell experienced in May to a series of rain events starting in early June. The transition from natural river state to reservoir conditions in 2023 did not appear to have a considerable impact on water temperatures overall, although the low water volume and relatively low tidal influence experienced under natural river state may allow waters to warm at similar rates as the stagnant water body that occurs when gates are closed under reservoir conditions. The unimpeded and high tidal flows that occur on the Kennetcook River are most likely the cause of the more moderate temperatures observed on that system. While the Avon River near the causeway is warmer in part due to the greater exposure of water to mudflats that are warmed by the sun for longer periods compared to areas further downstream, increased tidal flow would likely result in more moderate temperatures upstream of the Avon causeway resulting in a benefit to estuarine species.

Although gate operations are generalized into reservoir and natural river state, operations did not always provide consistent operations. Even a difference of a few minutes in gate openings can lead to changes in water quality. For example, although reservoir conditions occurred in 2020 and 2023, salinity upstream of the causeway under reservoir conditions varied considerably from fresh (near 0) to brackish (as high as 15.32). Differences in trends between YSI salinity and HOBO conductivity measurements at the Trunk 1 bridge may have been a result of a change in water depth of the HOBO logger after a data download, although further investigation would be valuable. Salinity immediately downstream of the causeway has also varied and has ranged from near 0 after mid tide (with the salt wedge forming up to approximately a kilometer downstream of the causeway) to well over 25. These large and unnatural swings in salinity near high tide are not common in estuaries and result in a lack of balance and disruptions to the ecosystem. *Corophium* for example have been shown to be killed after even a brief submersion in freshwater, and so there is likely a negative impact to the benthic community residing higher up the mud flats when these freshwater signals are detected near high tide. *Corophium* is relied on by thousands of migratory shorebirds that frequent the area in summer and fall, and so a negative impact on the benthic community would also negatively impact these migratory shorebirds.

Although only one year of data is available for gate operations where natural river state was provided and larger volumes of tide was permitted upstream (2021), this was the only year where all DO measurements remained above the Canadian water quality guidelines for the lowest acceptable DO concentrations in “warm water”. However, even under natural river state, DO levels measured by YSI upstream of the causeway remain much lower than those observed in the Kennetcook River estuary where full tidal flow provides greatly enhanced flushing and mixing of waters to improve the overall water quality. DO levels upstream of the causeway were notably lowest in years when reservoir conditions existed (2020 and 2023) and DO levels on the Avon have been observed to reach levels harmful and occasionally lethal to fish. Complications experienced with HOBO loggers make it difficult to interpret the high fluctuation observed in DO measurements, and periods of near 0mg/L are potentially a result of logger error or burial in sediment. Further investigation into logger complications would be beneficial in interpreting HOBO logger DO results. Further, although data gaps exist, the gates are closed during the low tide period under reservoir conditions and result in likely depletion of oxygen levels that are not sufficient for the conservation and protection of the fish and fish habitat. As such, conditions other than natural river state and full tidal flow result in negative impacts to water quality both upstream and downstream of the causeway that are not sufficient for the conservation and protection of fish and fish habitat.

Measurements of pH are consistently within CCME guidelines for estuarine systems and allude to the stability and health of the estuarine region on the Kennetcook River. The same is not true for the Avon River, especially under reservoir conditions. Measurements of pH appear to be largely influenced by salinities, especially where a large pH drop occurred both upstream and downstream of the causeway after a reservoir was maintained in June 2023. Natural river state conditions provided a much more consistent salinity upstream of the causeway after mid tide and eliminated the large downstream rush of freshwater that often occurs under reservoir conditions. As such, pH was also generally consistent upstream and downstream of the causeway after mid tide during natural river state, suggesting a balance or equilibrium had been achieved. Under reservoir conditions, gate operations were largely inconsistent with saltwater entry occurring sporadically resulting in highly variable pH upstream of the causeway. The contrast in pH stability between natural river state and reservoir conditions alludes to the lack of stability that occurs in this ecosystem under reservoir conditions.

Water sampling for *E. coli* showed fluctuating levels that exceeded Health Canada recreational water quality guidelines on three occasions throughout the sampling period beginning June 29 and ending October 26, 2023. On September 12, 2023, the West Hants Regional Municipality Committee of the Whole confirmed the likely source of *E. coli* stating that "during the last two years, combined sewer overflows have been identified for depositing debris and contents into the Pisiquid River/Lake". Committee of the Whole also carried a motion in that meeting stating "Committee of the Whole recommends council direct the CAO to engage staff to initiate communications following any combined sewer overflows (cso) over land or into water courses that occur within West Hants regional municipality to identify to the public the need for caution and potential risk to their health in the area the overflows occurred".

Habitat

HSI surveys completed upstream of the Avon causeway and on the Kennetcook River provide a baseline to compare against surveys completed in future years to determine if any changes in habitat conditions have occurred. Instream cover is largely present for fry but is scarcer for parr, especially on the Avon. Poor pool quality is a widespread issue in both watersheds with some sedimentation issues observed primarily in the Avon, and largely associated at sites adjacent to agricultural lands. Overall, habitat within close proximity of agricultural activities has been more negatively impacted than sites assessed in more forested regions. One reason for this includes cattle disturbing and eroding the bank along sections of the watercourse. Cattle have been observed within the Avon, Allen Brook and LeBreau Creek on several occasions since 2017 and the banks along these sections are observed to be extremely worn (Figure 21). Cattle within these watercourses may also be contributing alongside combined sewer overflow releases to the ongoing *E. coli* challenges upstream of the causeway. These habitat challenges offer good opportunities for rehabilitation or offsetting projects to improve these watercourses for fish and fish habitat.

Figure 21 Cattle causing degradation to fish habitat along the Avon and Allen Brook.

Water temperatures are rated to be suitable at nearly all HSI assessed sites in both watersheds. A pH of 5.5 or above has been shown to significantly reduce acid-related mortality in Atlantic salmon (Lacroix and Knox, 2005). DFO data from the 1980s show 34 of 65 Southern Upland rivers exhibited a mean annual pH below 5.1, and 14 of these rivers exhibited a pH below 4.7 and were thought to have extirpated salmon populations (DFO, 2000). The pH in freshwater regions upstream of the causeway and on the Kennetcook River measured throughout 2020-2023 suggests that the majority of these freshwater reaches have an adequate pH to support critically endangered inner Bay of Fundy Atlantic salmon. Note that a pH of 5.38 and 5.62 were recorded on the West branch Avon in 2023 suggesting this area is of potential concern to Atlantic salmon while pH on Tomcod River in the Kennetcook watershed measured 4.23 indicating this stream is of poor quality to Atlantic salmon.

Drastic differences in both the abundance and diversity of birds observed between upstream of the causeway and the other monitoring sites in the fall of 2023 is a good indicator of poor habitat quality upstream of the causeway at that time. It is noteworthy that while regular bird counts were not conducted in prior years under the Ministerial Order, there were regularly hundreds of ducks observed utilizing developing estuarine habitat between the causeway and Trunk 1 bridge between 2021 and 2023. A considerable number of geese were also regularly observed upstream of the trunk 1 bridge when the order was in place. *Corophium* and many fish species depend on estuarine habitat and are relied upon by thousands of migratory birds that travel through this region to fuel their migration. This sudden change in bird abundance and diversity strongly suggests that the re-establishment of the reservoir in June 2023 caused a substantial disruption to the habitat and breakdown of the ecosystems ability to support higher trophic levels.

6.4 Gaps and Lessons Learned

Large ranges in salinity cause disruptions in the ecosystem but the exact extent is unknown at the causeway site. Even short periods of exposure to freshwater has shown to kill corophium and so regular sampling of the benthic communities would be beneficial in assessing how gate operations are impacting salinity levels and subsequently the base of the local food web.

Data gap in DO during low tide, especially downstream of causeway.

While HOBO loggers provide a much higher data resolution then boat based YSI measurements, some challenges were experienced with HOBO loggers including:

-failure/early expiration of DO caps.
-data downloads not properly clear loggers of existing data although this duplication was corrected in analysis.
-occasional changes in date format when logging data required careful consideration in analysis.
-temporary removal of equipment from water was required for downloading data.
-loggers became temporary fouled (covered by algae, etc.).
-loggers were temporarily buried in sediment at times (for example, Station 8 Kennetcook following large storm).
-one logger was not able to be recovered due to an inability to access it after reservoir conditions were established upstream of the causeway.

While a good baseline of HSI data has been established, analysis would benefit from additional survey sites, especially on the Kennetcook River. A potential survey site likely exists near Stanley with perhaps additional sites present on the main river further upstream under low water conditions. The extent and quality of spawning habitat has not been thoroughly assessed at these sites and would also be beneficial when assessing if changes in habitat have occurred and subsequently impacted fish abundance.

Documenting bird abundance and diversity was a useful exercise in the fall of 2023 and should be continued in monitoring work moving forward.

7.0 Summary of Findings

7.1 Integrating Multiple Knowledge Systems

Working collaboratively with multiple knowledge systems has proven to increase the availability and quality of data available, reduce data gaps (from lapsed permitting or staff unavailability experienced in the past) and provide a clearer understanding of the impacts to fish and fish habitat likely caused by the structure and associated gate operations. This approach provides the best available science and should be the default approach for monitoring endeavors.

Each year of study further strengthens the understanding of how dependant this project is on each knowledge system. A thorough analysis could not be conducted without a sufficient academic skill set and suitable data, and the quality and quantity of data simply could not be achieved without a competent and qualified operator and crew with the knowledge of what gear to use and how to deploy it in a safe and efficient manner. Cultural teachings such as Netukulimk reminds the team to take pride in minimizing sampling related mortality and learning as much as we can from each fish so as not to be wasteful.

7.2 Assess Effectiveness of Fish Passage

7.2.1 CPUE

Fish passage cannot occur when gates are closed. Under reservoir conditions where gates are open even for 30 minutes near equalization results in absolute blockage of fish for 91.7% of the time. Suitable conditions including habitat characteristics, low enough downstream water velocities (head pressure) and the occurrence of a regular and sufficient ecological maintenance flow must be provided in order for fish to first be at the structure and secondly to facilitate safe passage.

Freshwater reservoir conditions allow the passage of very limited abundances of gaspereau and striped bass (seven gaspereau and one striped bass caught upstream of the causeway before May 21 in 2019) and pass few if any Atlantic tomcod.

Brackish reservoir conditions pass limited abundances of Atlantic tomcod, gaspereau and striped bass through the structure.

Natural river state with intentional saltwater entry passes Atlantic silverside, Atlantic tomcod, flounder, gaspereau, rainbow smelt, striped bass, and other estuarine species.

Estuarine species assemblage are present upstream of causeway under natural river state, but switch to freshwater assemblages under reservoir conditions.

Involuntary downstream passage of freshwater species (brown bullhead and even beaver) into estuarine conditions occurs when water is impounded upstream of the causeway.

Evidence of gaspereau successfully spawning upstream of causeway under natural river state is based on visual observations and catches of young of year. There is limited evidence supporting spawning of Atlantic tomcod based on the catch of two young of year upstream of the causeway although these may be a result of dispersal from spawning sites in adjacent rivers.

Four iBoF Atlantic salmon were captured in close vicinity to the Avon causeway since 2018 showing the persistence of this species on the Avon River. Two adults caught in 2022 were confirmed to be SARA listed iBoF Atlantic salmon and directly associated with the DFO Live Gene Bank through genetic analysis by DFO.

7.2.2 PIT and T-Bar Tag Recapture

A high degree of connectedness (fish movement) between rivers within the Avon estuary suggest impacts of tidal barriers are not isolated to resident populations but likely have impacts on at least American eel and Atlantic tomcod throughout the region.

Sufficient recaptures are necessary for advanced modeling to create encounter histories suitable for SCR models; many recapture histories, and multiple recaptures for some individuals, are required for robust analyses. As such, sufficient monitoring surveys need to be carried out to not only deploy a sufficient quantity of tags but to also provide opportunity to collect a sufficient quantity of tag recaptures.

Recapture data of some species is sufficient to determine movements through barriers and between rivers, as well as to model population estimates and survival, which has been conducted for American eel, Atlantic tomcod and striped bass. Data remains insufficient to assess gaspereau and rainbow smelt.

American eel were only detected to have passed through the causeway 97 times since 2019. Although detection data of eel passing through the structure is limited, the majority of American eel remain on the side of the causeway where they were initially captured and tagged, while a much smaller proportion of eel are observed to move through the causeway, suggesting a barrier to the free passage of American eel.

7.3 Assess Efficiency of Fish Passage

7.3.1 Damage and Mortality

Gaspereau, Atlantic tomcod and American eel were observed to incur the most damage under reservoir conditions when gates opened near equalization.

Gaspereau, Atlantic tomcod and American eel incurred less damage under natural river state.

Little damage was observed in other species mostly due to infrequent catches and low abundance.

7.3.2 Delays In Fish Passage

Gaspereau passage efficiency is highest when natural river state and intentional saltwater entry occurs and least efficient under reservoir conditions when gates are largely closed, or opened to release water downstream (during which flows are too high for gaspereau to swim against).

Although historically a large rainbow smelt run occurred on the Avon, low abundances of rainbow smelt are currently observed, which makes assessment of passage difficult. However, nearly all rainbow smelt were observed upstream of the causeway under natural river state with intentional saltwater entry.

Atlantic tomcod appear to require water to flow upstream of the causeway in order to pass with passage more efficient under natural river conditions and intentional saltwater entry. Several years of consistent operations under natural river state may be required to develop suitable spawning and rearing habitat.

Striped bass passage is largely a function of prey availability and as such striped bass will follow the prey species such as gaspereau. Inefficient passage and delays in migration of prey species may lead to unnatural rates or predation and a reduction in the productivity of the fisheries.

Gates were opened for a longer period in 2021 compared to 2022, allowing for a longer period of saltwater entry. Fish passage is observed to further improve with increased saltwater entry.

7.3.3 Acoustic Tagging

Given that both the 180 kHz and 307 kHz systems perform well, there is a clear advantage in using the 180 kHz system as this is the only system where pressure tags are available to provide a depth position, and there are also numerous tagged fish and receivers utilizing the 180 kHz system that have already been deployed.

The existing 180 kHz receiver infrastructure and tag deployments can be used to compliment and expand the knowledge gained through acoustic tagging and receiver deployments at the causeway.

The trial deployment was successful and data quality is sufficient to justify an acoustic program under the monitoring plan. Such a program will help enable an understanding of fish behaviour at the structure and address if and when passage is being attempted and the number of passage attempts made through the structure by representative species (American eel, Atlantic salmon, Atlantic tomcod and gaspereau).

7.4 Evaluate Changes in Fish Habitat

7.4.1 Water Quality

Lack of natural tidal flow upstream of causeway likely contributes to higher temperature ranges.

Gate operations have large impact on salinities both upstream and downstream of causeway. Regular and large fluctuations in salinity upstream, especially under reservoir conditions create unstable conditions and disruptions to the ecosystem. Gate operations can result in unnaturally fresh waters downstream of the causeway with the salt wedge occasionally being pushed as far as several kilometers downstream of causeway under high runoff events, especially if reservoir is maintained. This leads to potential harm to benthic community, including species such as *Corophium* that is depended on by migratory shorebirds.

DO minimums are lowest under reservoir conditions and improve notably under natural river state, especially with increased tidal flow. Lack of downstream flows when gates are closed likely depleting DO levels and causing conditions insufficient for the conservation and protection of fish and fish habitat.

pH measurements provided further insight confirming that higher water quality stability occurs under natural river state conditions with instability occurring under reservoir conditions. Overall, pH levels consistently remain within CCME estuarine guidelines on the Kennetcook River but fail on the Avon River, especially under reservoir conditions.

High *E.coli* levels were observed through testing in 2023, which exceeded Health Canada guidelines on several occasions. An expected point source of this contamination is from a combined sewer outflow in downtown Windsor.

Increased tidal flow would benefit overall water quality.

7.4.2 Fish Habitat

Poor pool quality is a widespread issue in both watersheds with some sedimentation issues observed primarily in the Avon, and largely associated at sites adjacent to agricultural lands. Such sites present good opportunities for habitat remediation of offsetting projects.

Good cover for fry was identified at most sites along with suitable water temperatures. Good riffle-run substrate was also identified in forested regions largely associated with regions further upstream in both watersheds.

pH was assessed as suitable for Atlantic salmon at all sites other than on the West branch Avon (pH 5.38) and Tomcod River (pH 4.23) in the Kennetcook Watershed.

Hundreds to upwards of 1000 birds (typically geese and ducks) were often observed on the Kennetcook River and downstream of the Avon causeway in fall 2023 while few to zero were observed upstream of the causeway. This is compared to hundreds of birds observed upstream of the causeway under natural river state in previous years. This drastic reduction in bird abundance and diversity upstream of the causeway strongly suggests that the re-establishment of the reservoir in June 2023 caused a substantial disruption to the habitat and breakdown of the ecosystems ability to support higher trophic levels.

8.0 Conclusions and Next Steps

Specific objectives, the activities carried out or proposed to satisfy these objectives and the current progress status and recommended action items for each objective are outlined in Table 23. A summary table outlining specifics on passage effectiveness, efficiency and the respective confidence for each species under three general gate operational scenarios is provided in Table 24. Based on observations and knowledge gathered to date, this table also describes passage as active or passive, if the species has been observed to be damaged or killed at the causeway, what the respective catch windows have been and details on known migration cues and recommended action(s) for future monitoring at this site as it pertains to each species.

Table 23 Status of Objectives

Objective	Key Response Variables	Progress Status in 2023-2024	Action Items
Objective 1 – Integrating Multiple Knowledge Systems	-Maintain the collaboration of multiple knowledge systems including integrated planning, monitoring, analysis and interpretation of results.	Ongoing	Promote ongoing integration and collaboration of expert knowledge holders.
Objective 2 – Assess Effectiveness of Fish Passage	-Determine fish species presence and relative abundance (e.g., catch per unit effort) upstream and downstream of the Avon causeway and on the Kennetcook River throughout all ice-free months.	Ongoing	Continue boat-based monitoring at sufficient frequency to ensure adequate data is available for analysis.
	-Assess success of entry, passage through, and exit up and down the fishways throughout the tidal cycle. -Assess length of time it takes fish to enter and move up or down the fishway. -Assess fish survival rates from all sources through a capture-mark-recapture study.	Trial and Error[1]	Determine a suitable number of acoustic tags to deploy in each species. Deploy tags and receivers at the Avon causeway. This may also be addressed with PIT tags although installation of antennas on the current structure is likely not feasible, but antennas can likely be designed into future infrastructure if approved.

Objective 3– Assess Efficiency of Fish Passage	-Evaluate the magnitude and scope of any potential damage occurring to fish that pass through the causeway and on the Kennetcook river, including a high-level assessment of cumulative effects.	Ongoing	Continue boat-based monitoring at sufficient frequency to ensure adequate data is available for analysis.
	-Assess differences in mean CPUE between upstream and downstream of the causeway (a significant difference would suggest inefficient passage).		Continue boat-based monitoring at sufficient frequency to ensure adequate data is available for analysis. Continue development of a model to assess statistical differences in CPUE between sites and surveys.
	-Assess differences in run time (delays in migration) between the two rivers (an extended migration at the causeway compared to the Kennetcook river would suggest inefficient passage).		Continue boat-based monitoring at sufficient frequency to ensure adequate data is available for analysis. Continue development of a model to assess statistical differences in CPUE between sites and surveys.
	-Assess behaviour of fishes interacting with structure. Is passage being attempted? -Assess number of passage attempts made through the structure made by representative species (American eel, Atlantic salmon, Atlantic tomcod and gaspereau).	Trial and Error[1]	Determine a suitable number of acoustic tags to deploy in each species. Deploy tags and receivers at the Avon causeway.

Objective 4 – Evaluate Changes in Fish Habitat	-Assess changes in and suitability of water quality (e.g., surface water salinity, temperature, dissolved oxygen levels, turbidity, and concentration of total suspended sediments).	Ongoing	Continue monitoring with YSI, secchi disc and HOBO loggers.
	-Assess changes in and suitability of fish habitat (e.g., spatial extents of saltwater and suspended sediment intrusion, changes in assessed habitat suitability index),		Update HSI surveys at each site to assess changes in habitat. Sampling of species in different trophic levels and assessing the carbon and nitrogen isotopic composition provides a means to determine changes in the food web and nutrient sources.

1 Trial and Error indicates a period intended to identify specific methods and locations suitable for implementation in the Avon and Kennetcook Rivers.

Table 24 Summary of Passage by Species

Species	Passage Effectiveness*	Level of Certainty	Passage Efficiency**	Level of Certainty	Passage	Level of Certainty	Confirmed Damaged	Confirmed Mortality	Current Spawning on Avon River	Historic Spawning on Avon River	Catch Window	Migration Cues	Further Monitoring Requirements
Alewife	Natural River State: High; Brackish Reservoir: Medium; Freshwater Reservoir: Low	High; High; High	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: Low	High; High; High	Active	High	Y	Y	Y	Y	April - August	Spring: temperature, moon phase, water flow	Ongoing CPUE, continued PIT tag deployment for increased detections
Blueback Herring	Natural River State: High; Brackish Reservoir: Medium; Freshwater Reservoir: Low	High; High; High	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: Low	High; High; High	Active	High	Y	-	Y	Y	April - June	Spring: temperature, moon phase, water flow	Ongoing CPUE, continued PIT tag deployment for increased detections
Gaspereau	Natural River State: High; Brackish Reservoir: Medium; Freshwater Reservoir: Low	High; High; High	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: Low	High; High; High	Active	High	Y	Y	Y	Y	April - October	Spring: temperature, moon phase, water flow	Ongoing CPUE, continued PIT tag deployment for increased detections
American Eel	Natural River State: High; Brackish Reservoir: Medium; Freshwater Reservoir: Low	Medium; Medium; Medium	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: Low	Medium; Medium; Medium	Active/Passive	Medium	Y	Y	N	N	April - December	Spring: temperature	Continued PIT tag deployment for increased detections
American Shad	Natural River State: Low; Brackish Reservoir: None; Freshwater Reservoir: None	Medium; Medium; High	Natural River State: Low; Brackish Reservoir: None; Freshwater Reservoir: None	Medium; Medium; High	Active	High	Y	N	Unknown	Y	April - August	Spring: temperature, moon phase	Ongoing CPUE, continued PIT tag deployment for increased detections

Atlantic Menhaden	Natural River State: Low; Brackish Reservoir: None; Freshwater Reservoir: None	Medium; Medium; Medium	Natural River State: Low; Brackish Reservoir: None; Freshwater Reservoir: None	Medium; Medium; Medium	Active	High	Y	N	N	N	July - October	-	Ongoing CPUE, continued PIT tag deployment for increased detections
Atlantic Salmon	CPUE too low to assess	-	CPUE too low to assess	-	Active	High	N	N	Unknown	Y	June - July	Water flow	Ongoing CPUE
Atlantic Silverside	Natural River State: Medium; Brackish Reservoir: None; Freshwater Reservoir: None	Medium; Medium; Medium	Natural River State: Medium; Brackish Reservoir: None; Freshwater Reservoir: None	Medium; Medium; Medium	Unknown	-	Y	Y	Unknown	Unknown	May, July - August,	Unknown	Ongoing CPUE
Atlantic Sturgeon	CPUE too low to assess	-	CPUE too low to assess	-	Active	High	N	N	N	N	June	-	Ongoing CPUE
Atlantic Tomcod	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: None	High; High; High	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: None	High; High; High	Passive	High	Y	N	Unknown	Unknown	April - January	Late fall/ early winter - temperature, moon phase	Ongoing CPUE, continued PIT tag deployment for increased detections
Brook Trout	CPUE too low to assess	-	CPUE too low to assess	-	Active	High	N	N	Y	Y	April, December,	Moon phase and water flow	Ongoing CPUE
Brown Bullhead	Freshwater species not seeking passage	-	Freshwater species not seeking passage	-	Passive	High	Y	N	Unknown	Unknown	April, May, August -	-	Ongoing CPUE to assess impacts of changing habitats

Flounder	Natural River State: Medium; Brackish Reservoir: None; Freshwater Reservoir: None	Medium; High; High	Natural River State: Medium; Brackish Reservoir: None; Freshwater Reservoir: None	Medium; High; High	Unknown	-	N	N	Unk now n	Unk now n	April - November	Unknown	Ongoing CPUE, continued PIT tag deployment for increased detections
Green Crab	Natural River State: Low; Brackish Reservoir: Low; Freshwater Reservoir: None	High; High; High	Natural River State: Low; Brackish Reservoir: Low; Freshwater Reservoir: None	High; High; High	Unknown	-	N	N	Unk now n	Unk now n	April, July - November	-	Ongoing CPUE
Mummichog	Natural River State: Unknown; Brackish Reservoir: Unknown; Freshwater Reservoir: Unknown	-	Natural River State: Unknown; Brackish Reservoir: Unknown; Freshwater Reservoir: Unknown	-	Unknown	-	N	N	Unk now n	Unk now n	May - November	Unknown	Ongoing CPUE
Rainbow Smelt	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: None	High; High; High	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: None	High; High; High	Unknown	-	N	N	Unk now n	Y	April, May, September -	Spring: temperature, moon phase, water flow	Ongoing CPUE, continued PIT tag deployment for increased detections
Sand Shrimp	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: None	High; Medium; High	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: None	High; Medium; High	Passive	High	N	N	Unk now n	Unk now n	April - July, September -	Unknown	Ongoing CPUE
Sea Lamprey	CPUE too low to assess	-	CPUE too low to assess	-	Active	High	N	N	Unk now n	Unk now n	May	Unknown	Ongoing CPUE
Smallmouth Bass	Freshwater species not seeking passage	-	Freshwater species not seeking passage	-	Passive	High	N	N	Unk now n	Unk now n	April, June - November	-	Ongoing CPUE to assess impacts of changing habitats

Striped Bass	Natural River State: High; Brackish Reservoir: Medium; Freshwater Reservoir: Low	High; High; High	Natural River State: Medium; Brackish Reservoir: Low; Freshwater Reservoir: Low	High; High; High	Active	High	Y	Y	Unknown	Unknown	April - October	-	Ongoing CPUE, continued PIT tag deployment for increased detections
Stickleback	Natural River State: Unknown; Brackish Reservoir: Unknown; Freshwater Reservoir: Unknown	-	Natural River State: Unknown; Brackish Reservoir: Unknown; Freshwater Reservoir: Unknown	-	Passive	Medium	N	N	Unknown	Unknown	April, June - November	Unknown	Ongoing CPUE
White Perch	Natural River State: Unknown; Brackish Reservoir: Unknown; Freshwater Reservoir: Unknown	-	Natural River State: Unknown; Brackish Reservoir: Unknown; Freshwater Reservoir: Unknown	-	Active	High	Y	N	Unknown	Unknown	April - December	Unknown	Ongoing CPUE
White Sucker	Freshwater species not seeking passage	-	Freshwater species not seeking passage	-	Passive	High	Y	Y	Y	Y	April - January	-	Ongoing CPUE to assess impacts of changing habitats
Yellow Perch	Freshwater species not seeking passage	-	Freshwater species not seeking passage	-	Passive	High	N	N	Unknown	Unknown	April - June, August,	-	Ongoing CPUE to assess impacts of changing habitats

* Zero passage occurs when gates are closed, which for reference occurs for 91.5% of the time if gates are open for 30 minutes, four times a day. ** Passage cannot be efficient if it is not effective.

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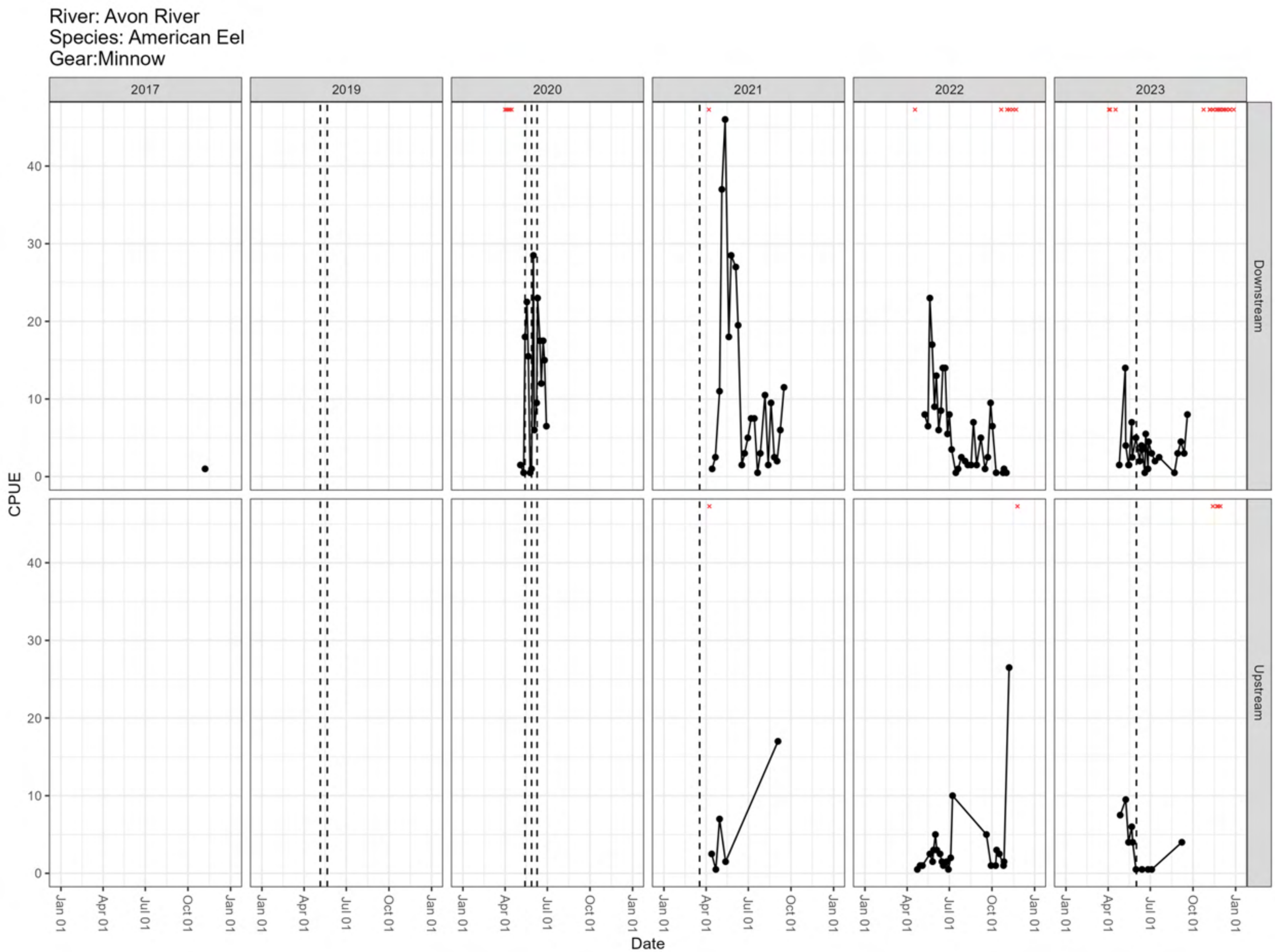
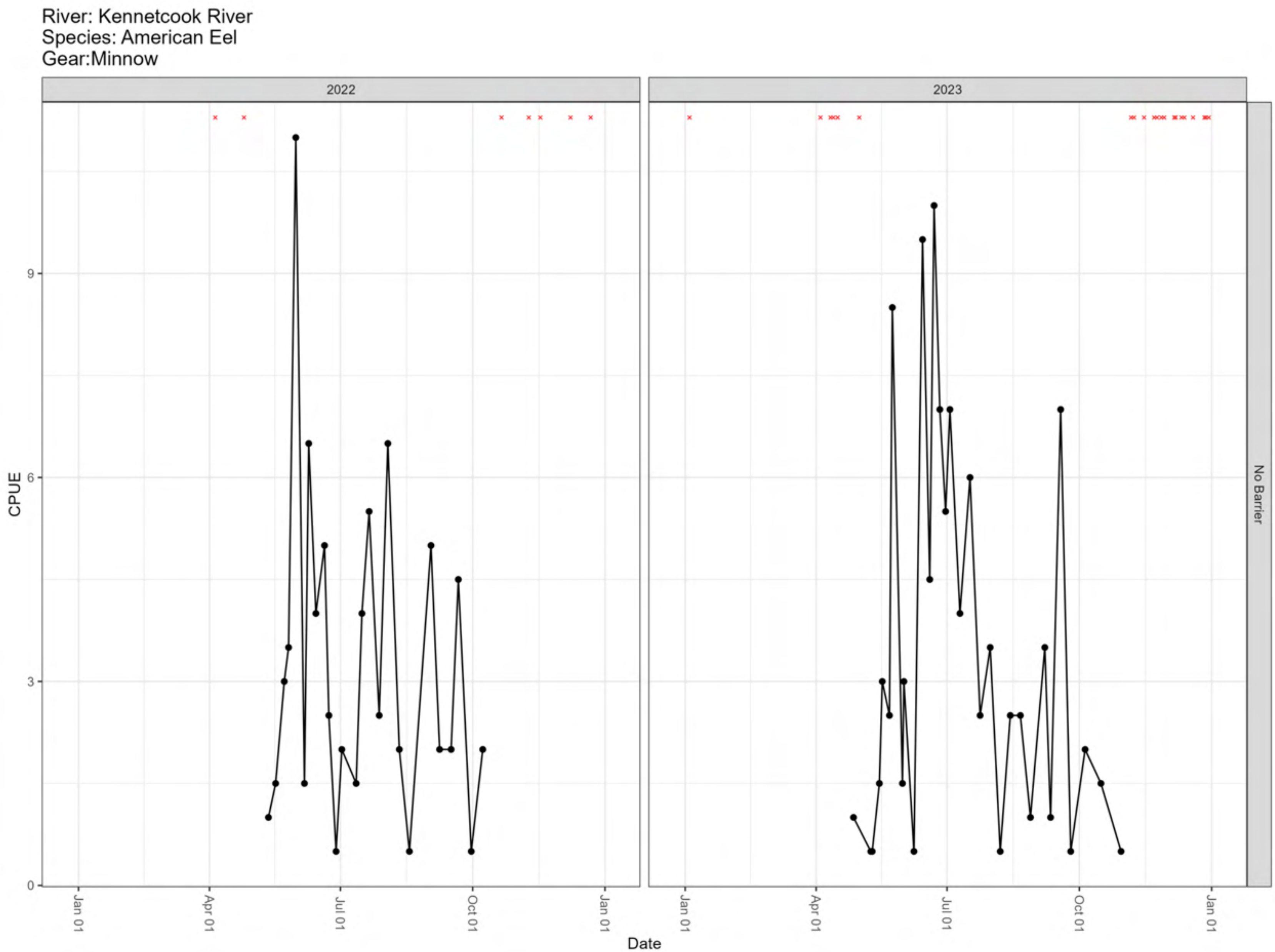
Appendix A – Summary CPUE

Red x's indicate dates when fishing events occurred but did not result in the capture of the target species.

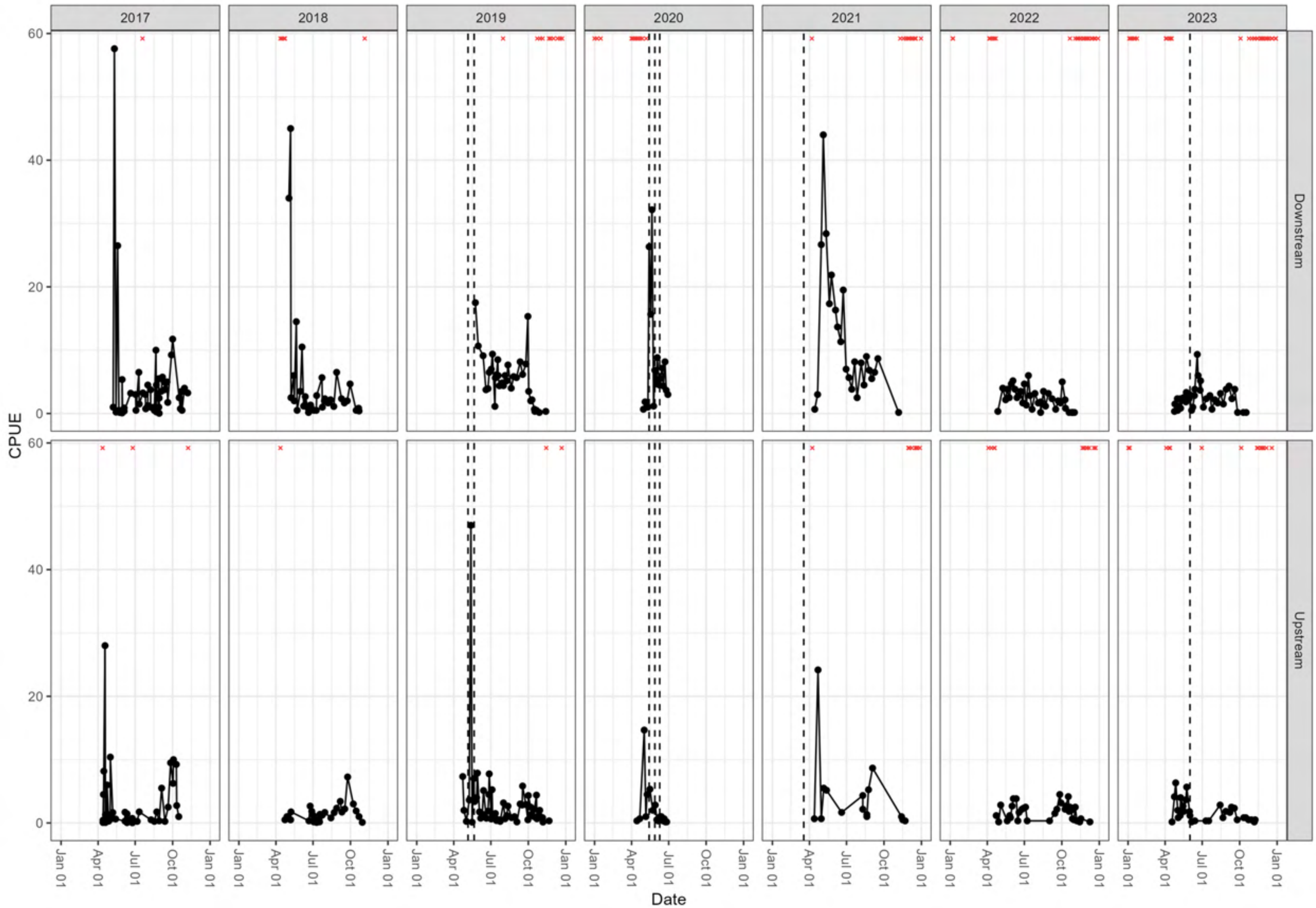
Vertical dashed lines represent notable events for gate operations:

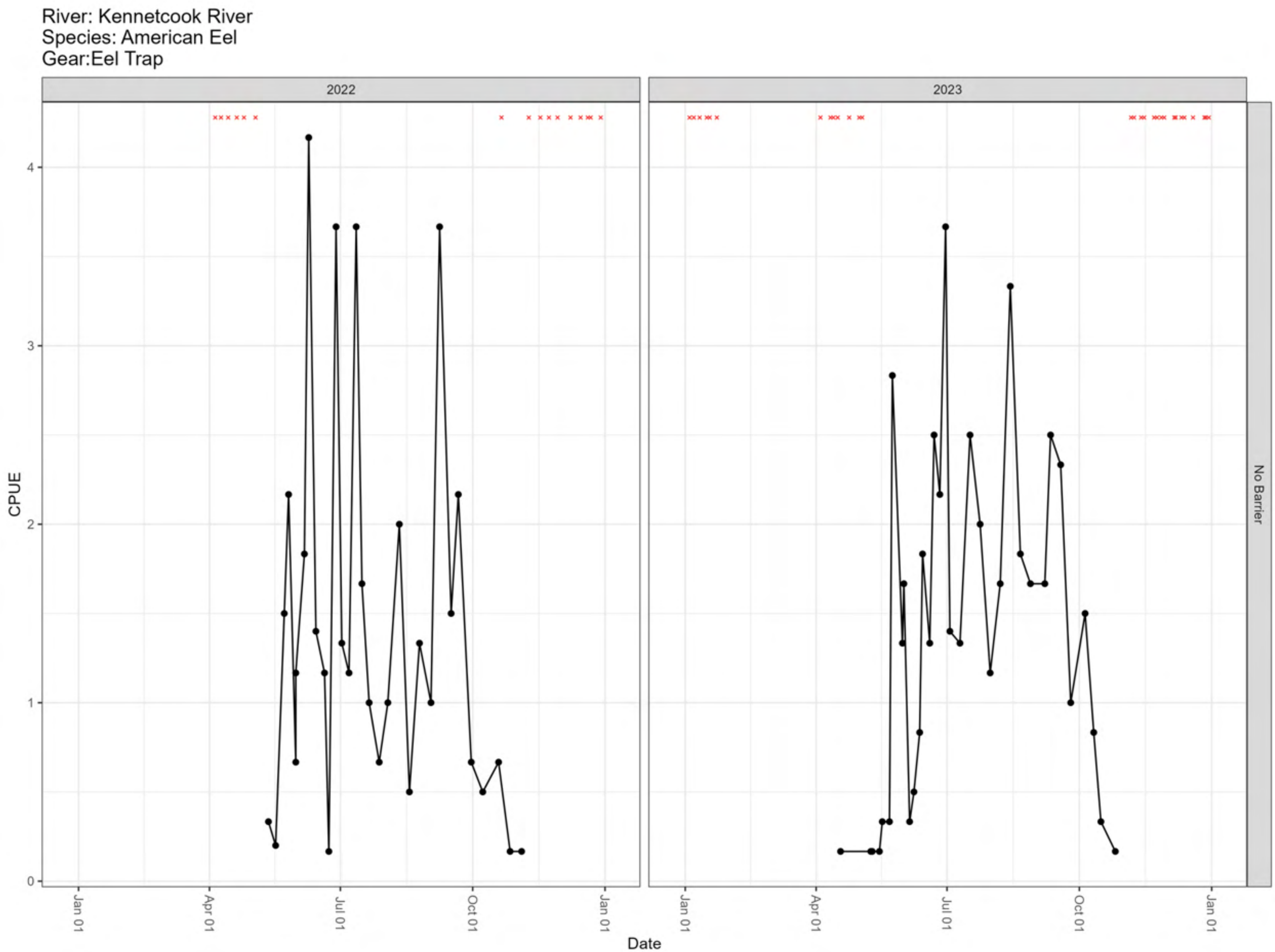
-May 6, 2019 (reservoir level dropped for maintenance on one tide)
-May 21, 2019 (reservoir dropped and began providing fish passage for about 1 week)
-May 14, 2020 (first Ministerial Order issued)
-May 28, 2020 (reservoir established)
-June 9, 2020 (reservoir level raised, some saltwater entry occurred until Sept 2020)
-March 18, 2021 (second Ministerial Order issued)
-June 1, 2023 (provincial State of Emergency issued, reservoir established)

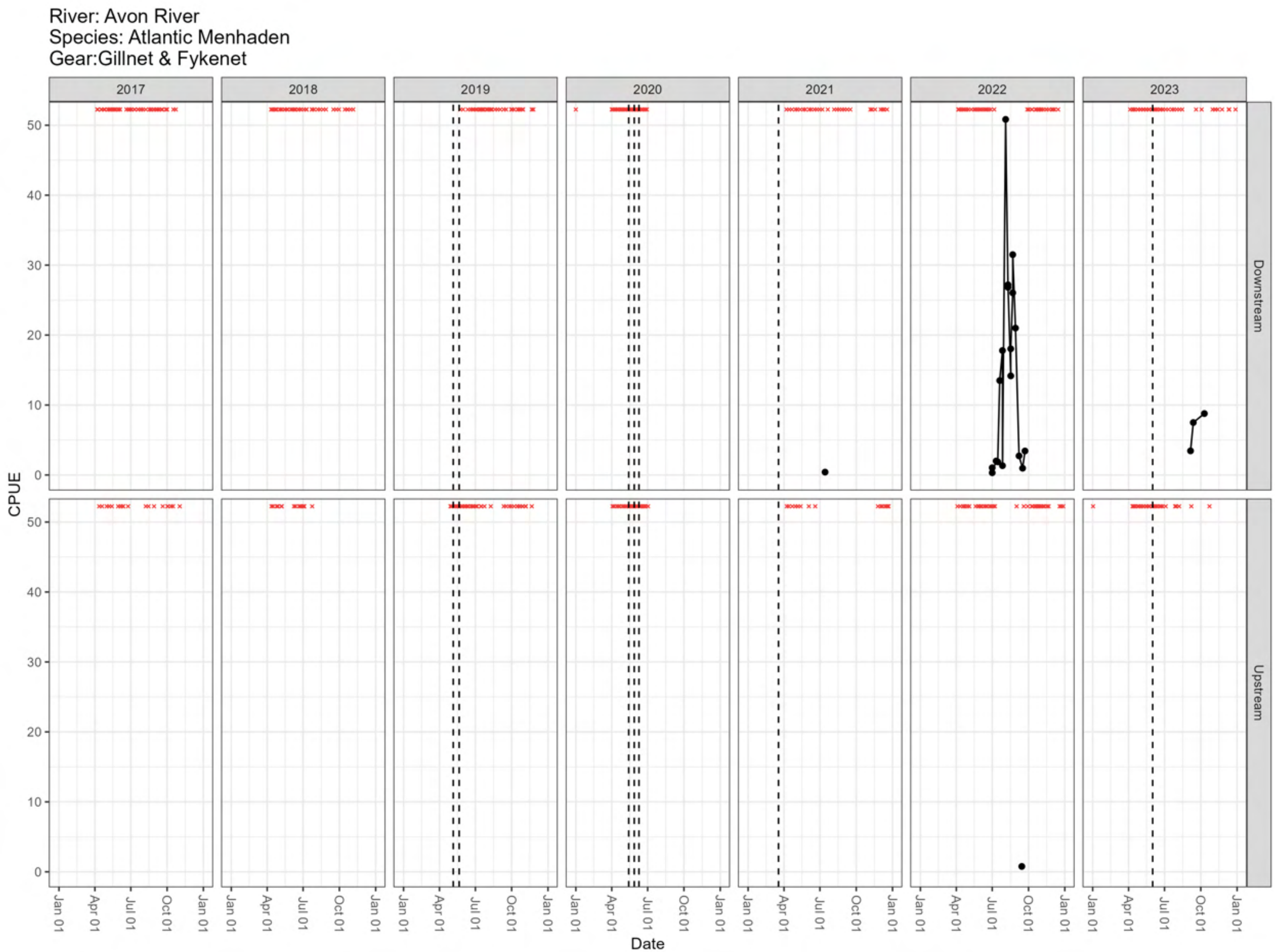

River: Avon River
Species: American Eel
Gear:Minnow
2017
2019
2020
2021
2022
2023
Downstream
Upstream
CPUE
0
10
20
30
40
Jan 01
Apr 01
Jul 01
Oct 01
Date

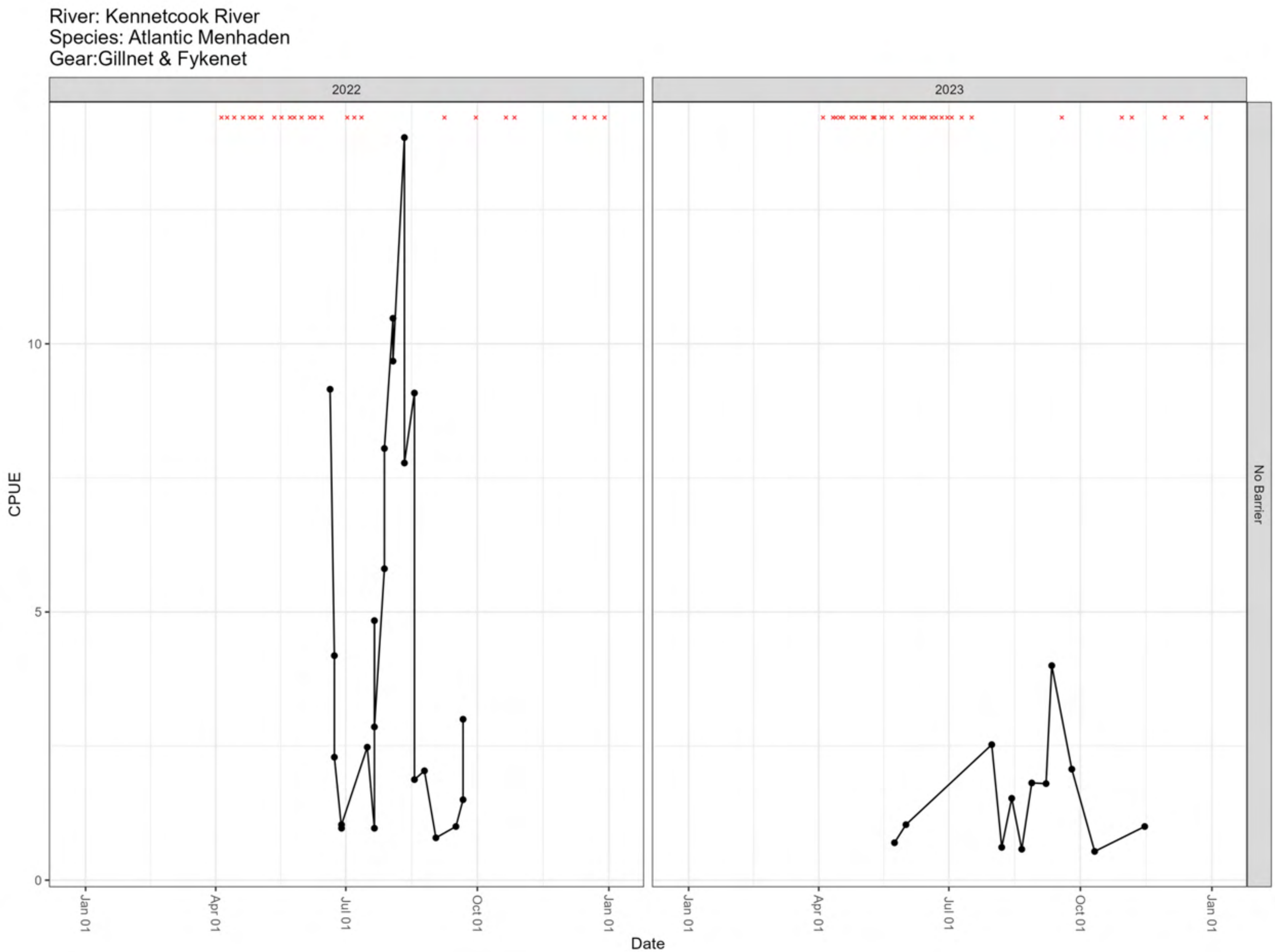

River: Kennetcook River
Species: American Eel
Gear:Minnow
2022
2023
CPUE
0
3
6
9
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01
Date
No Barrier

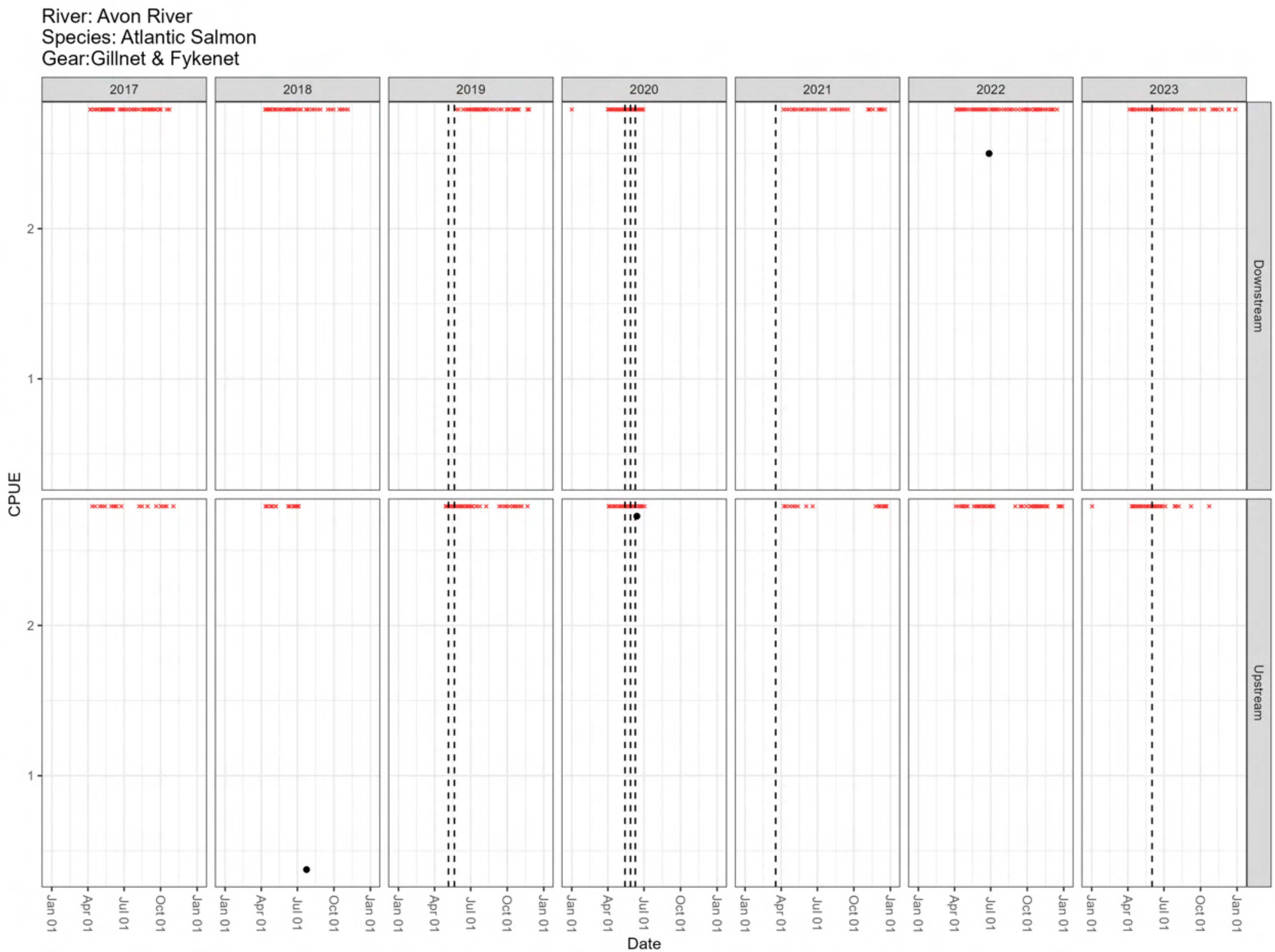
River: Avon River
Species: American Eel
Gear:Eel Trap




River: Kennetcook River
Species: American Eel
Gear:Eel Trap
2022
2023
No Barrier
CPUE
0
1
2
3
4
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01
Date

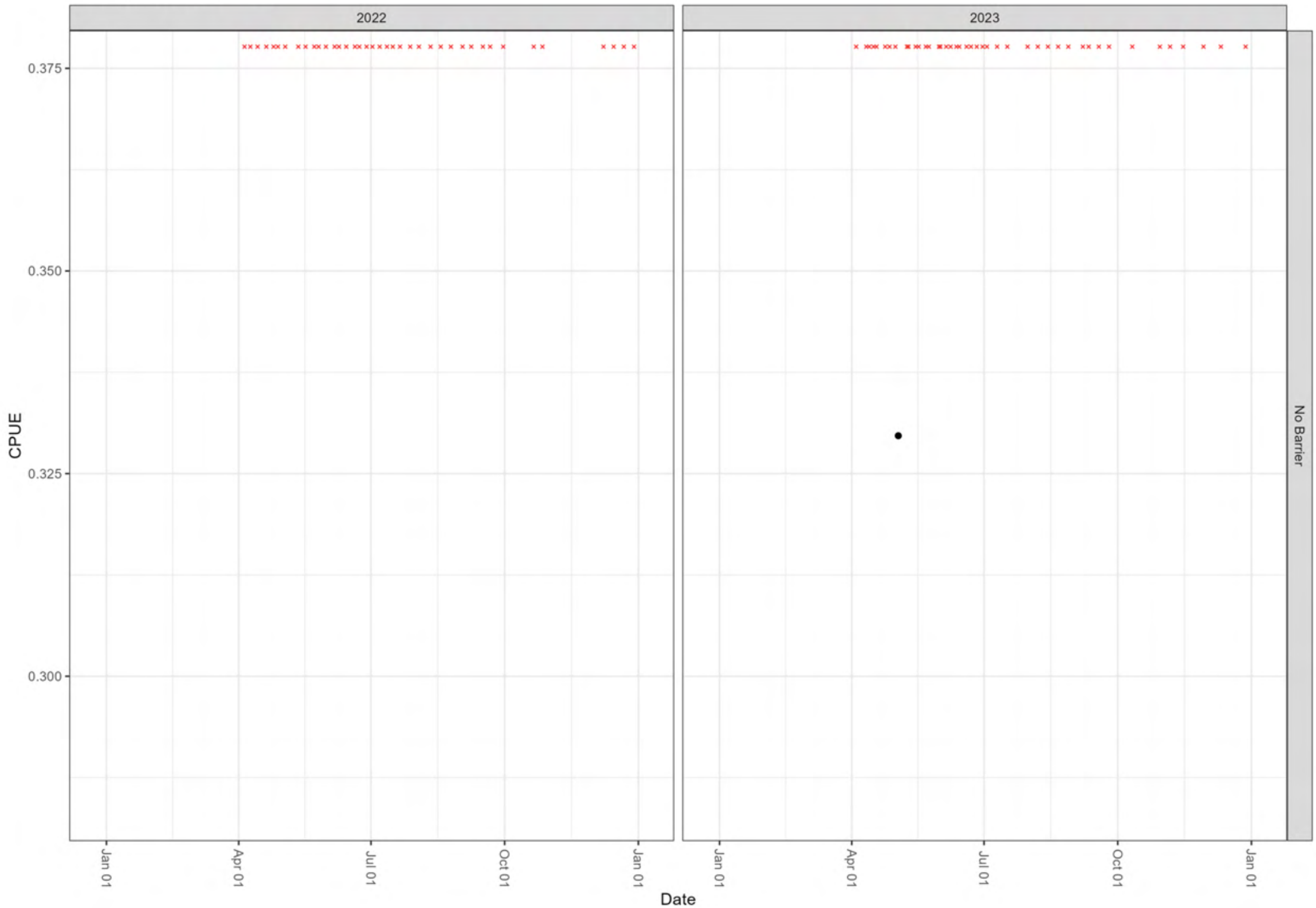

River: Avon River
Species: Atlantic Menhaden
Gear:Gillnet & Fykenet
2017
2018
2019
2020
2021
2022
2023
Downstream
Upstream
CPUE
0
10
20
30
40
50
Date
Jan 01
Apr 01
Jul 01
Oct 01

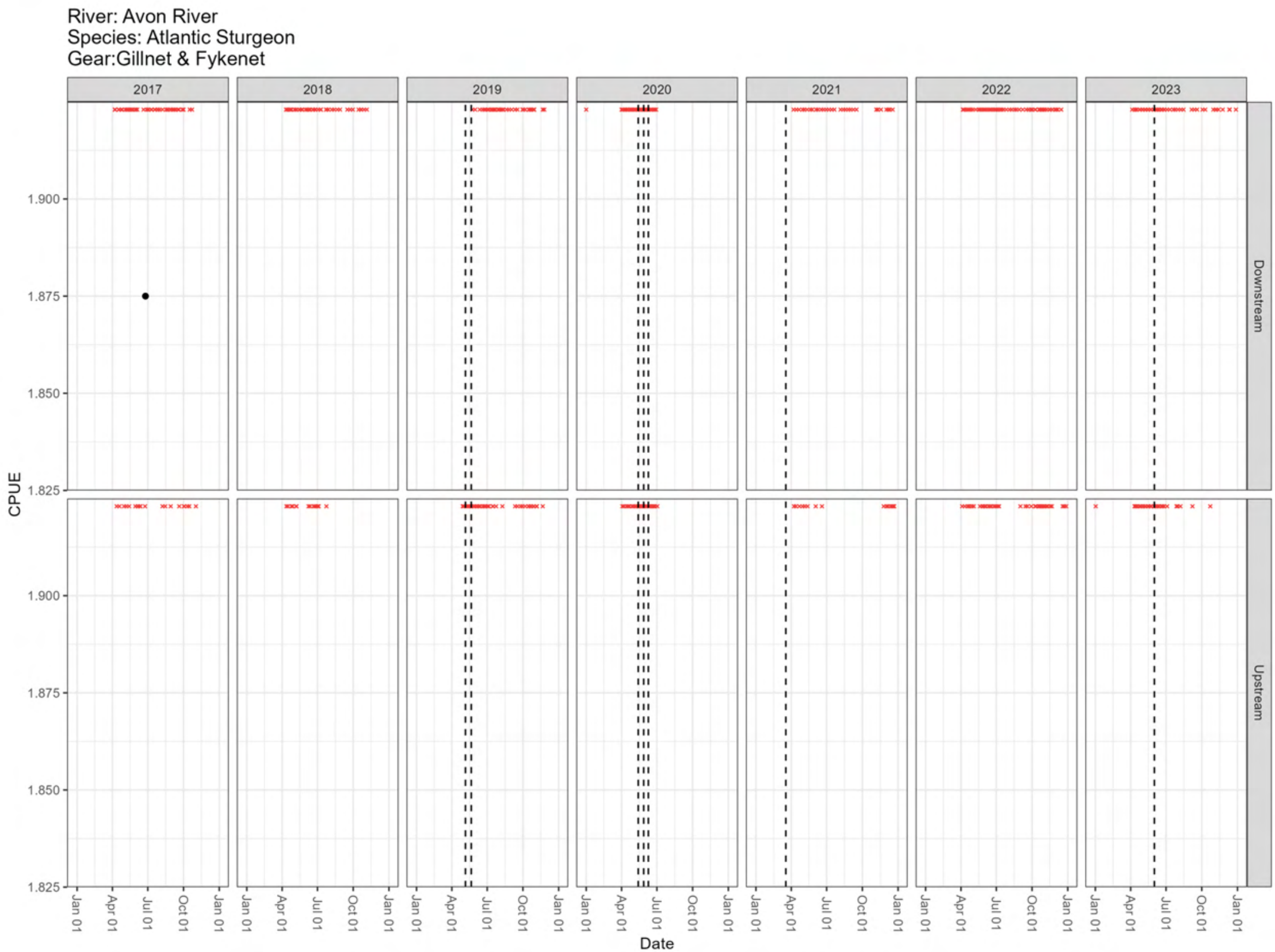

River: Kennetcook River
Species: Atlantic Menhaden
Gear:Gillnet & Fykenet
2022
2023
No Barrier
CPUE
0
5
10
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01
Date



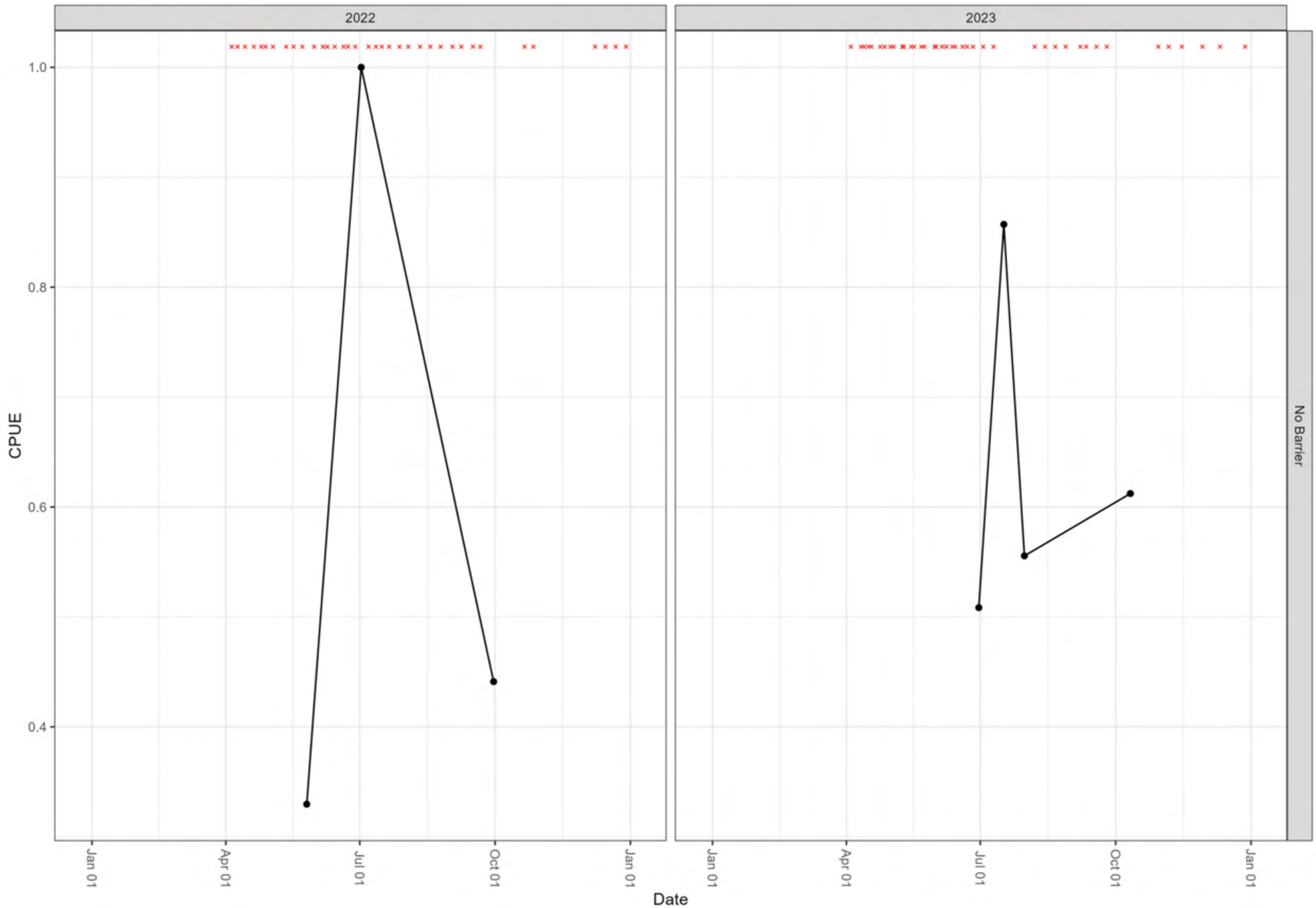
River: Avon River
Species: Atlantic Salmon
Gear:Gillnet & Fykenet
2017
2018
2019
2020
2021
2022
2023
Downstream
Upstream
CPUE
2
1
Jan 01
Apr 01
Jul 01
Oct 01
Date

River: Kennetcook River
Species: Atlantic Salmon
Gear:Gillnet & Fykenet

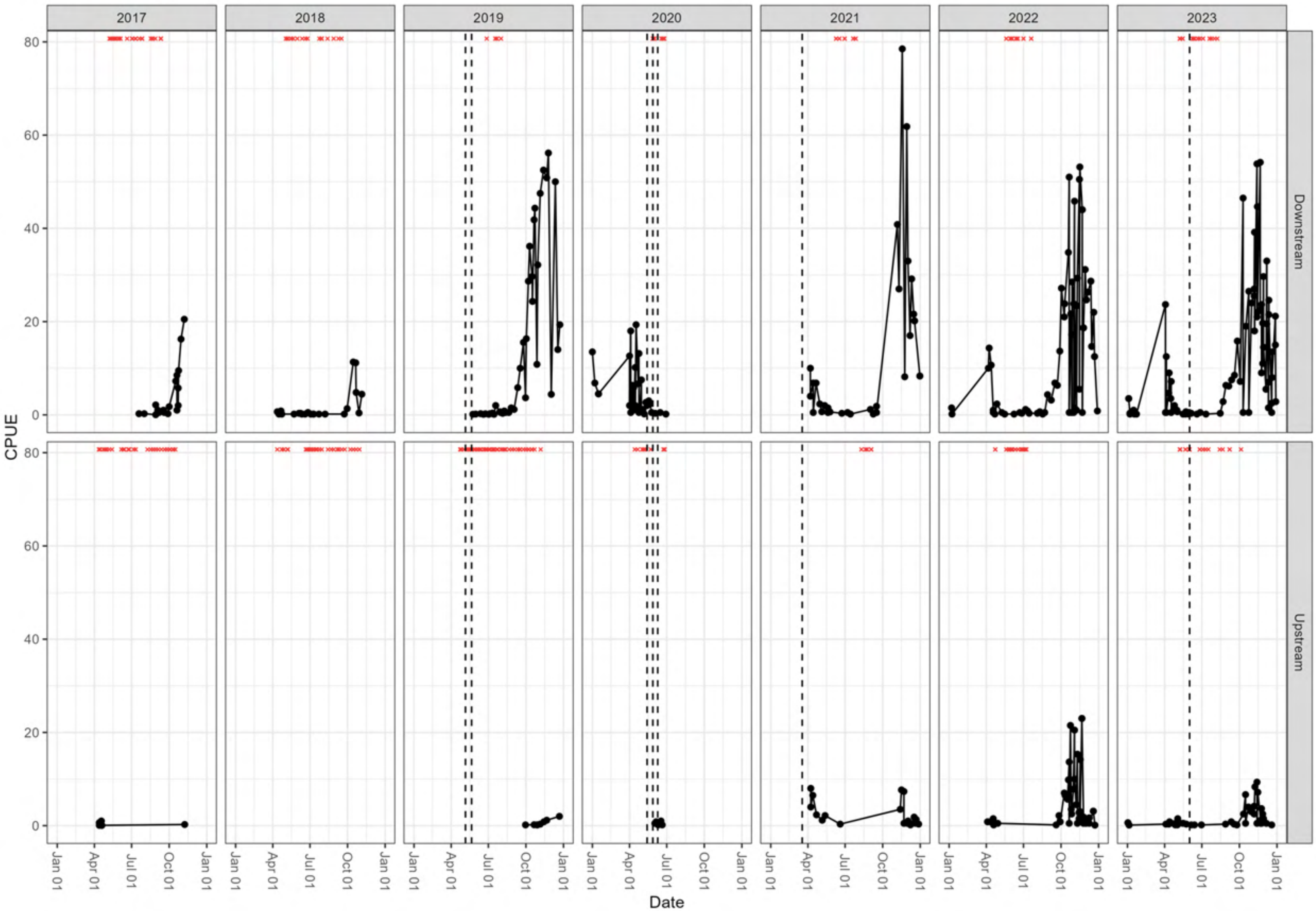



River: Avon River
Species: Atlantic Sturgeon
Gear:Gillnet & Fykenet
2017
2018
2019
2020
2021
2022
2023
Downstream
Upstream
CPUE
1.900
1.875
1.850
1.825
Jan 01
Apr 01
Jul 01
Oct 01
Date

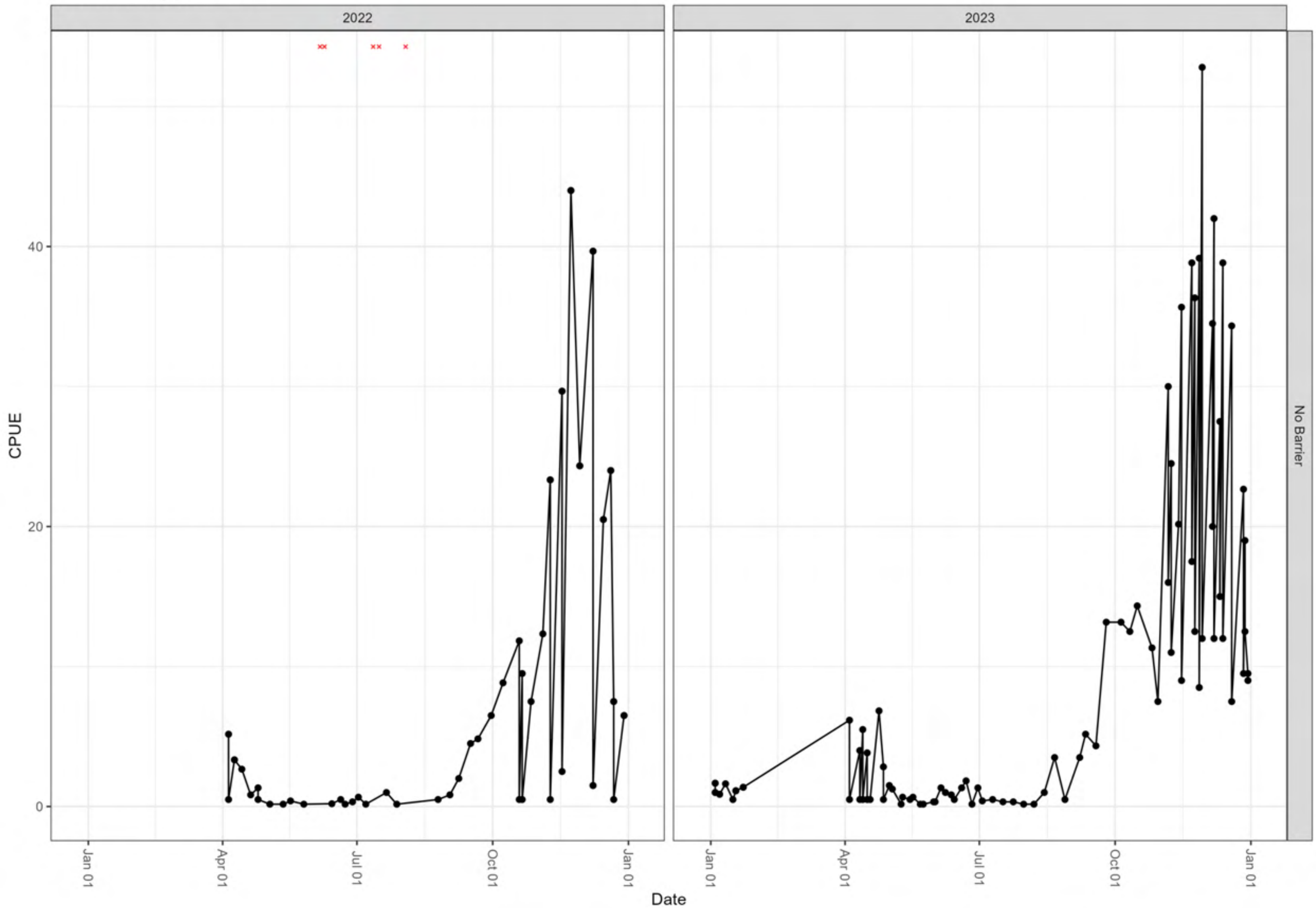
River: Kennetcook River
Species: Atlantic Sturgeon
Gear:Gillnet & Fykenet

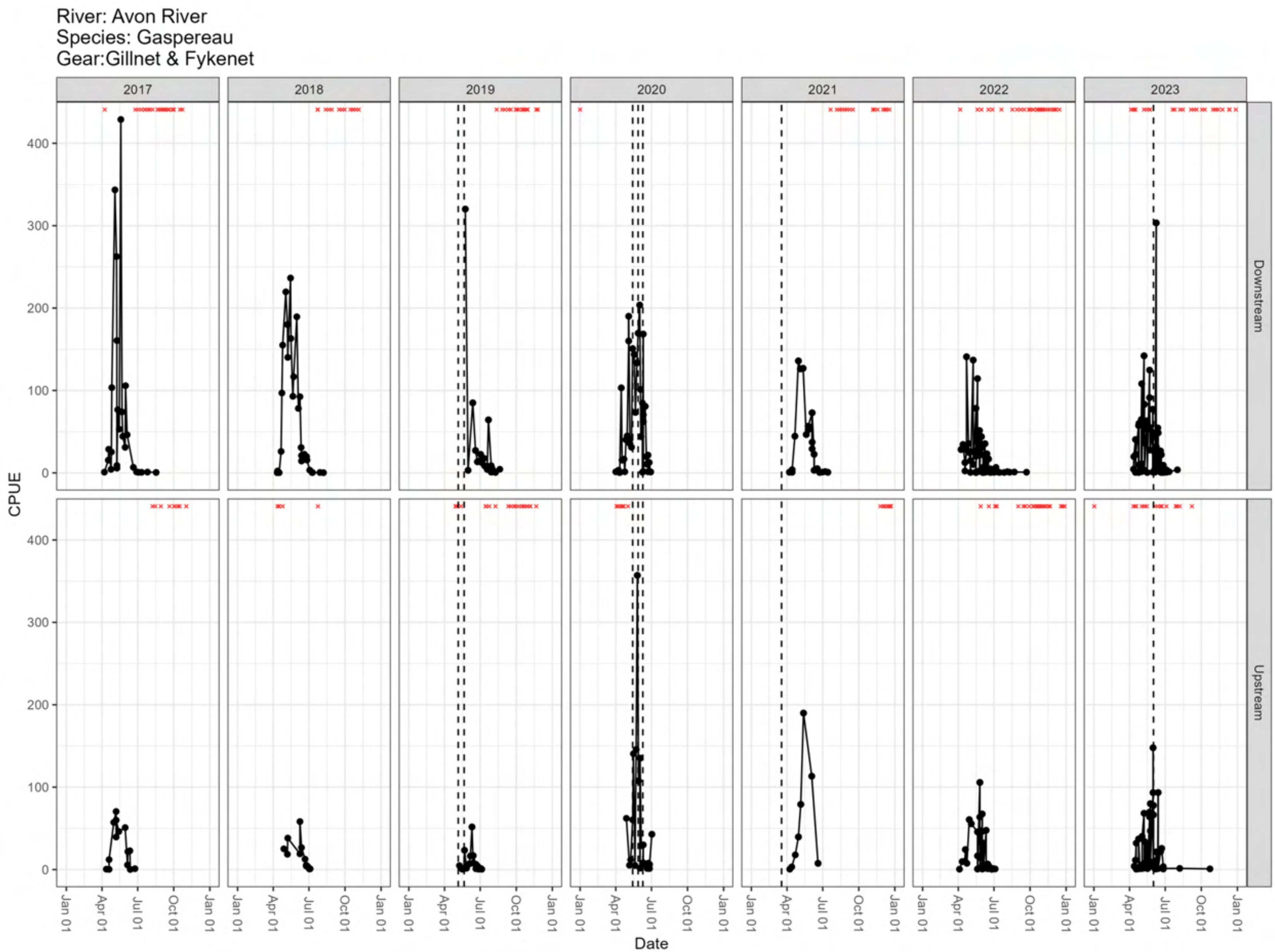


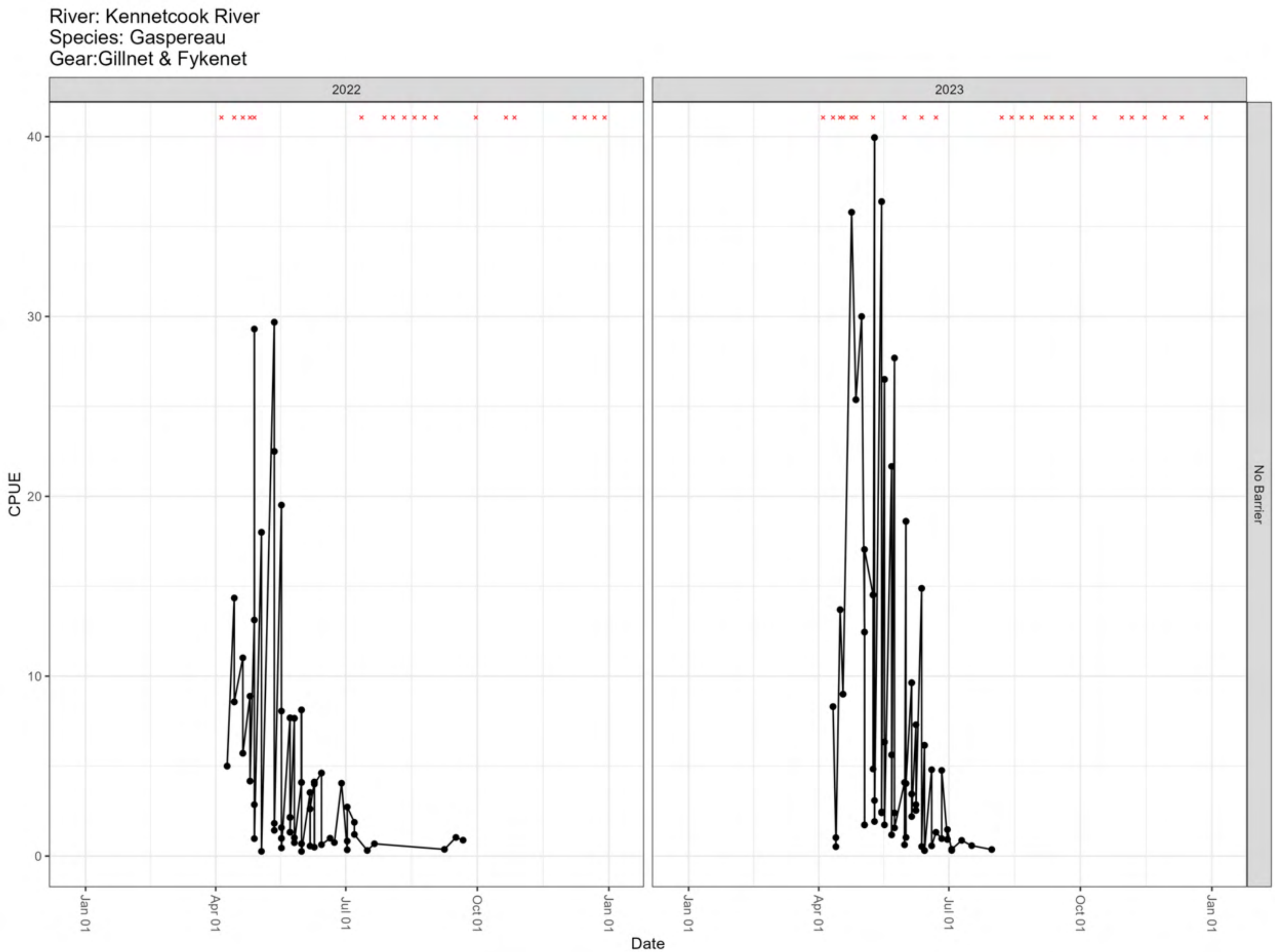
River: Avon River
Species: Atlantic Tomcod
Gear:Eel Trap & Minnow



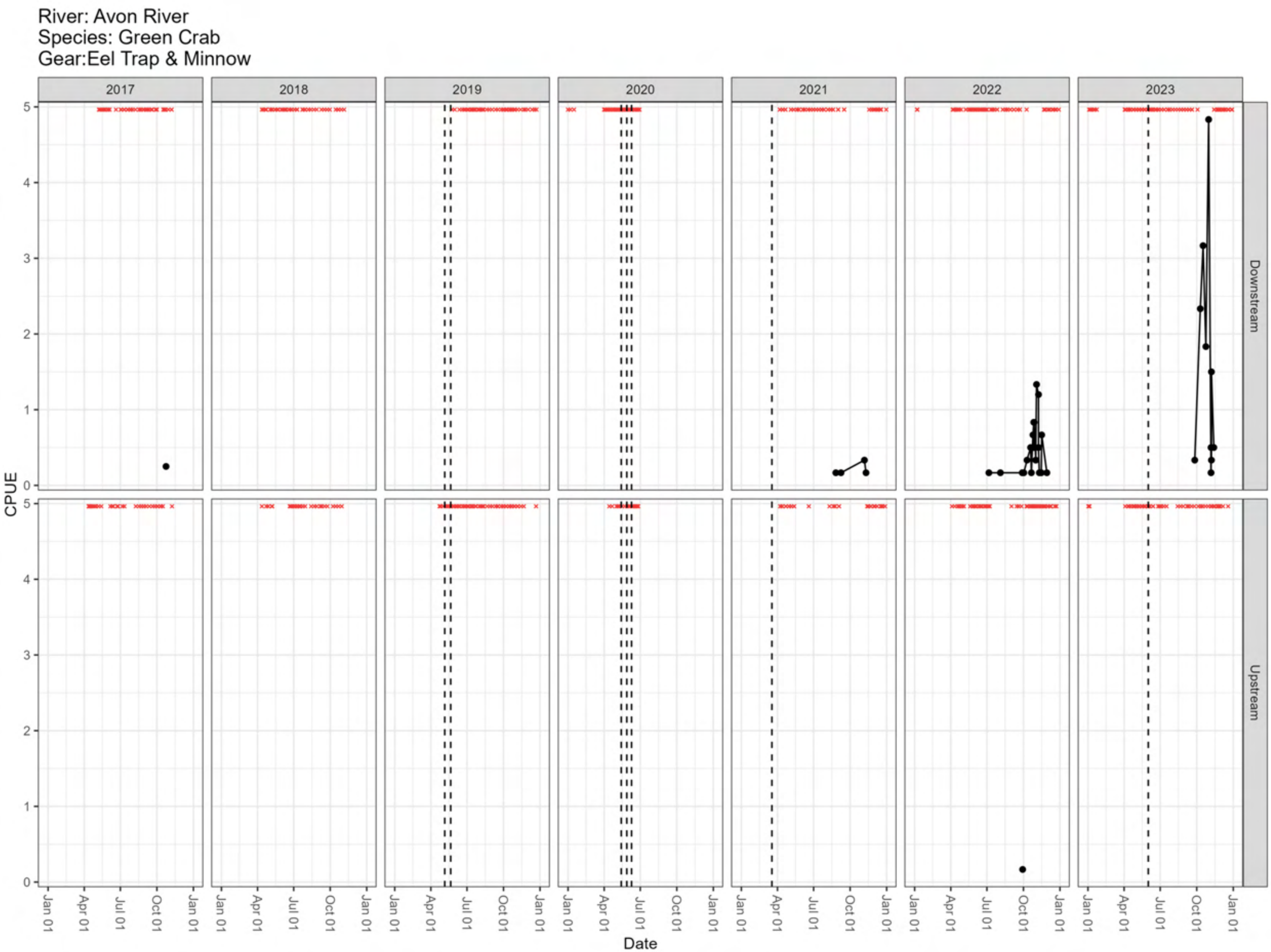
River: Kennetcook River
Species: Atlantic Tomcod
Gear:Eel Trap & Minnow

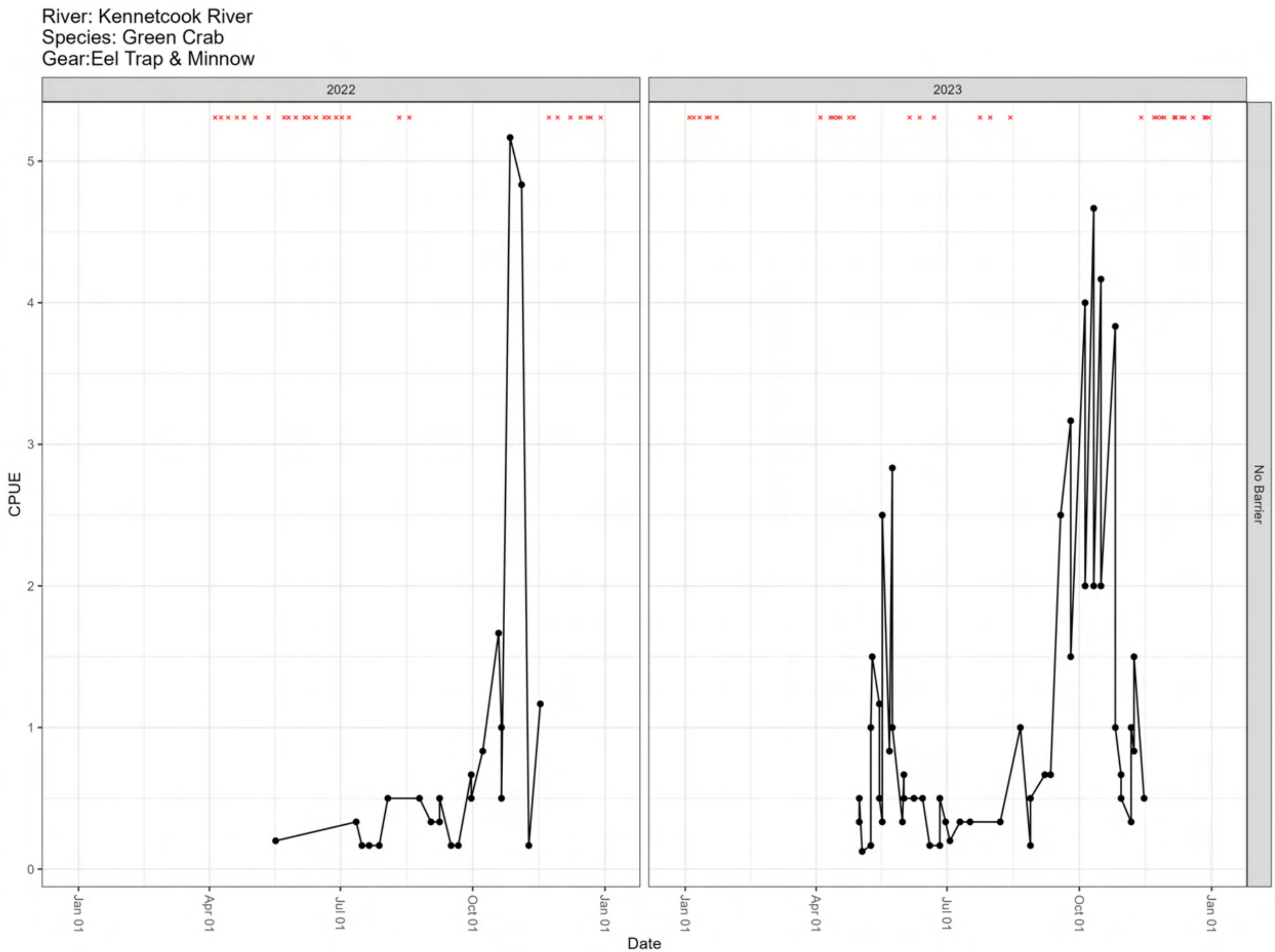



River: Avon River
Species: Gaspereau
Gear:Gillnet & Fykenet
2017
2018
2019
2020
2021
2022
2023
Downstream
Upstream
CPUE
0
100
200
300
400
Jan 01
Apr 01
Jul 01
Oct 01
Date

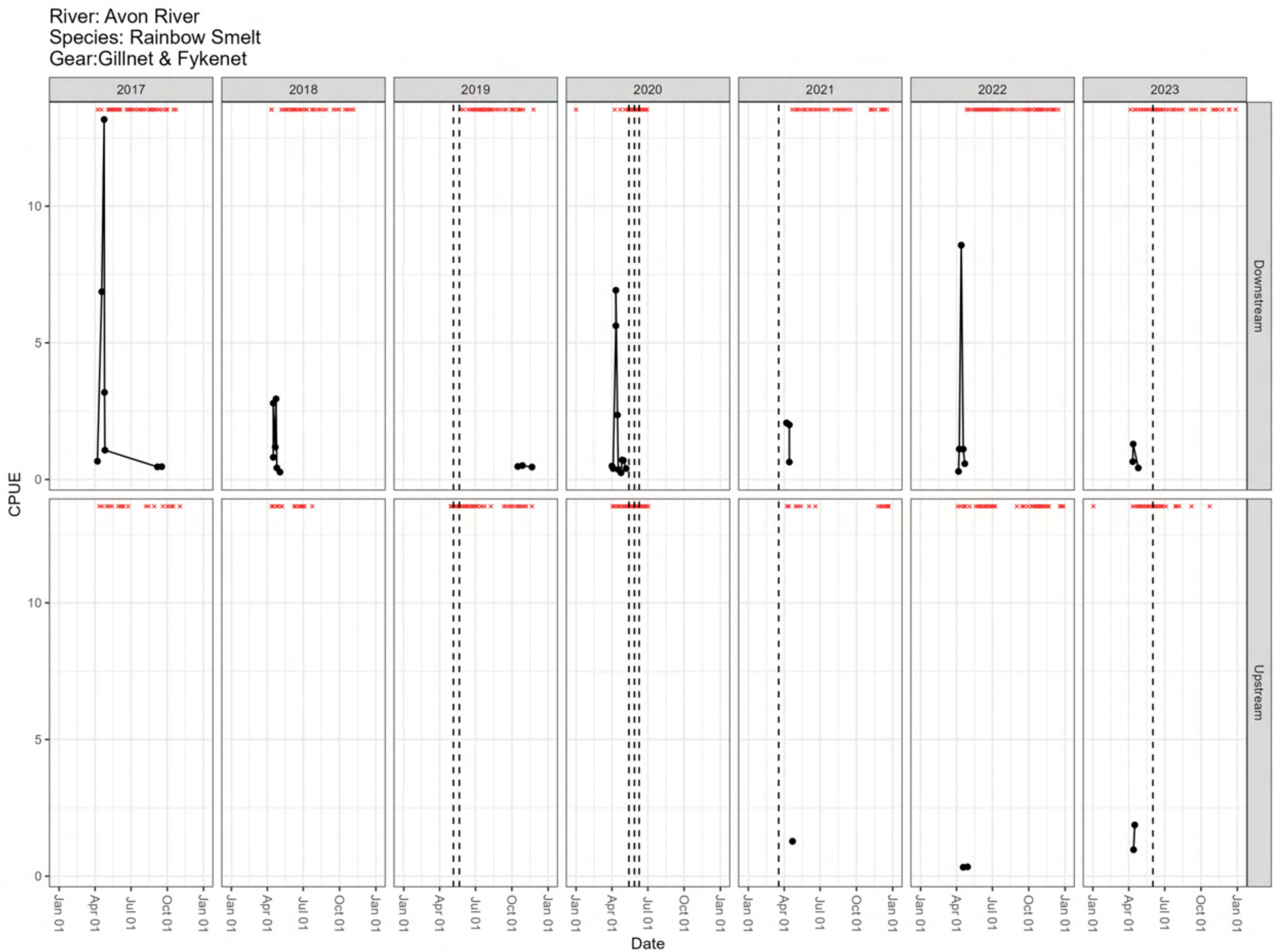


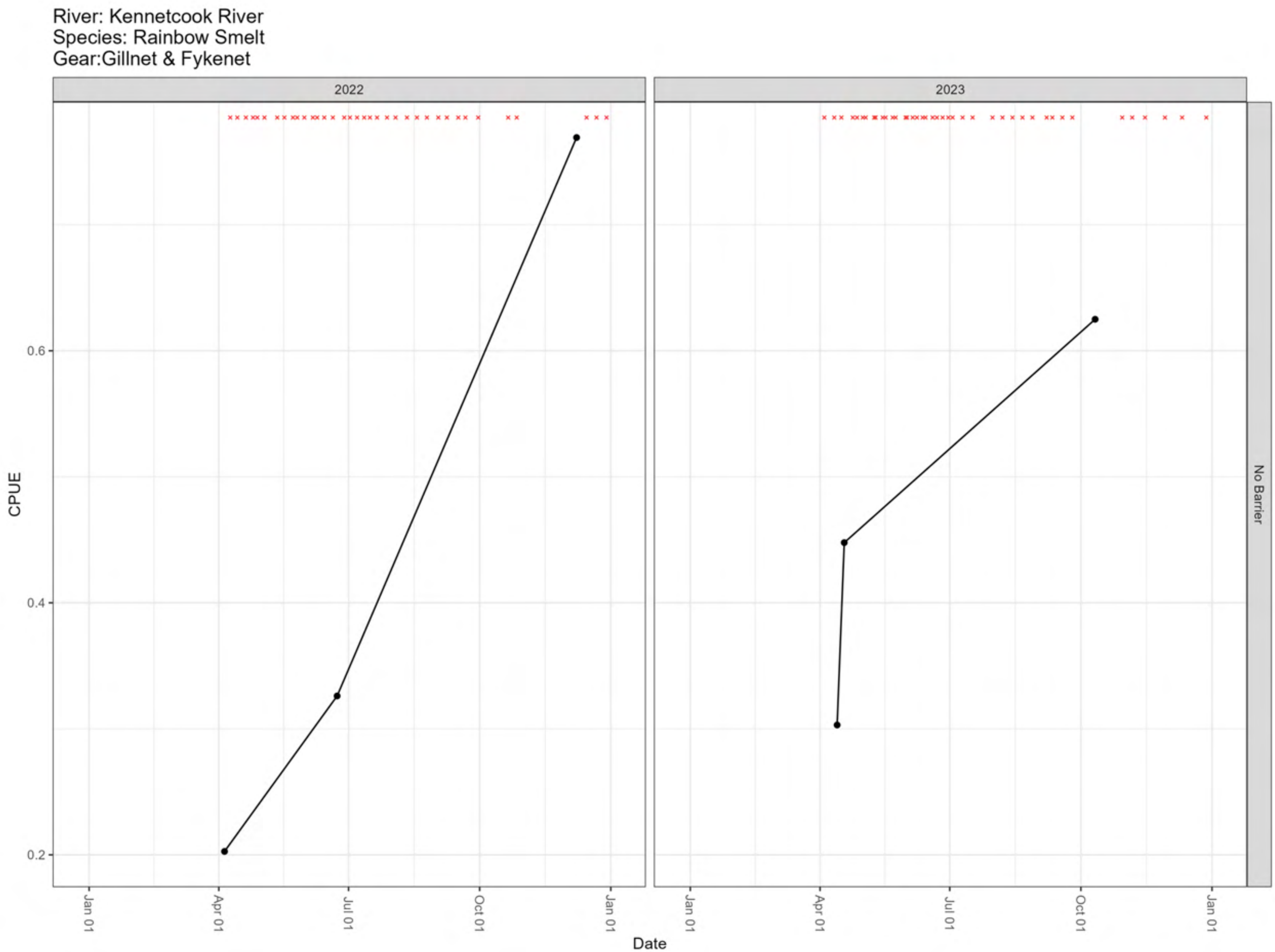
River: Kennetcook River
Species: Gaspereau
Gear:Gillnet & Fykenet
2022
2023
No Barrier
CPUE
0
10
20
30
40
Date
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01


River: Avon River
Species: Green Crab
Gear:Eel Trap & Minnow
2017
2018
2019
2020
2021
2022
2023
Downstream
Upstream
CPUE
0
1
2
3
4
5
Jan 01
Apr 01
Jul 01
Oct 01
Date

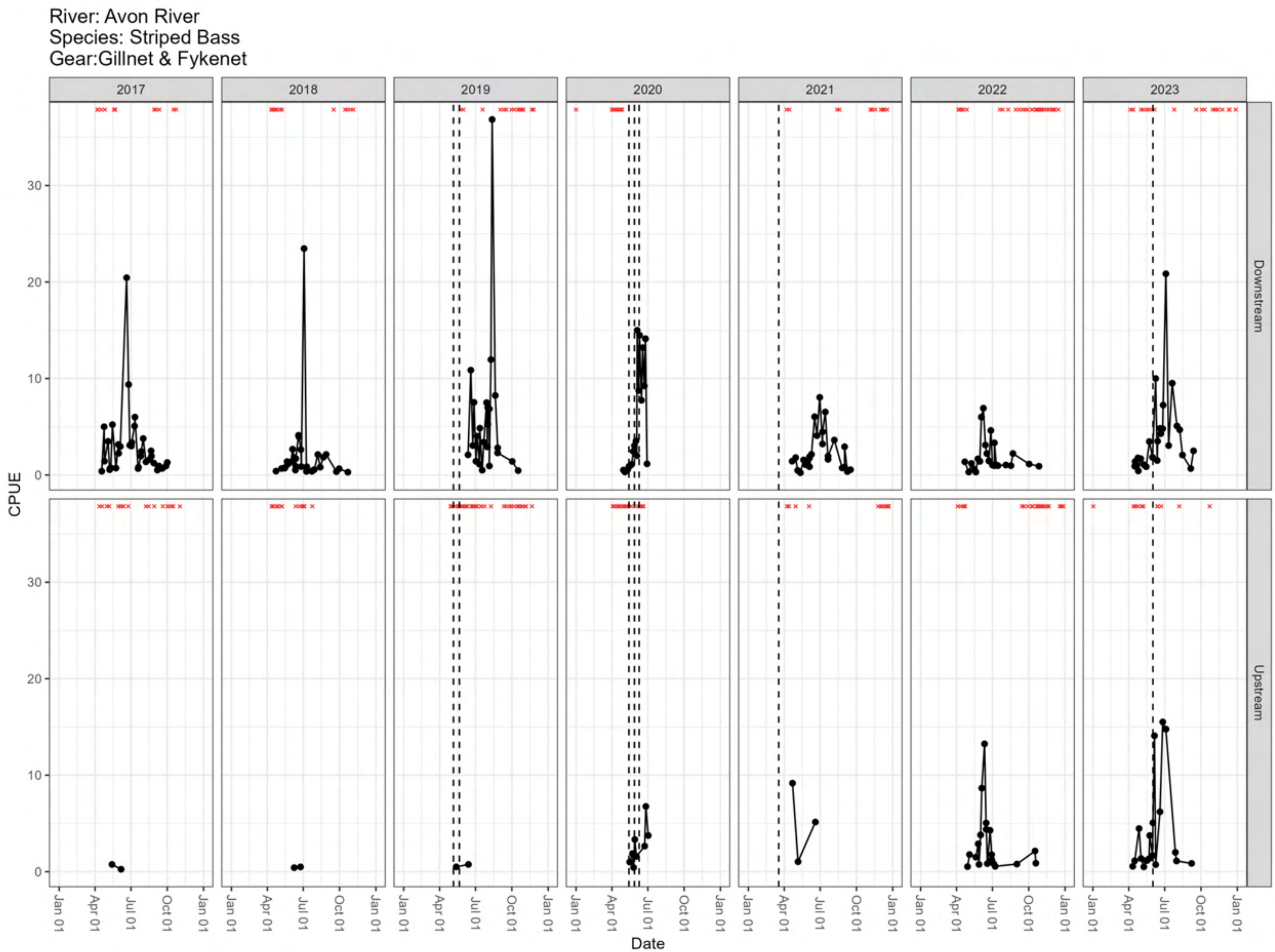


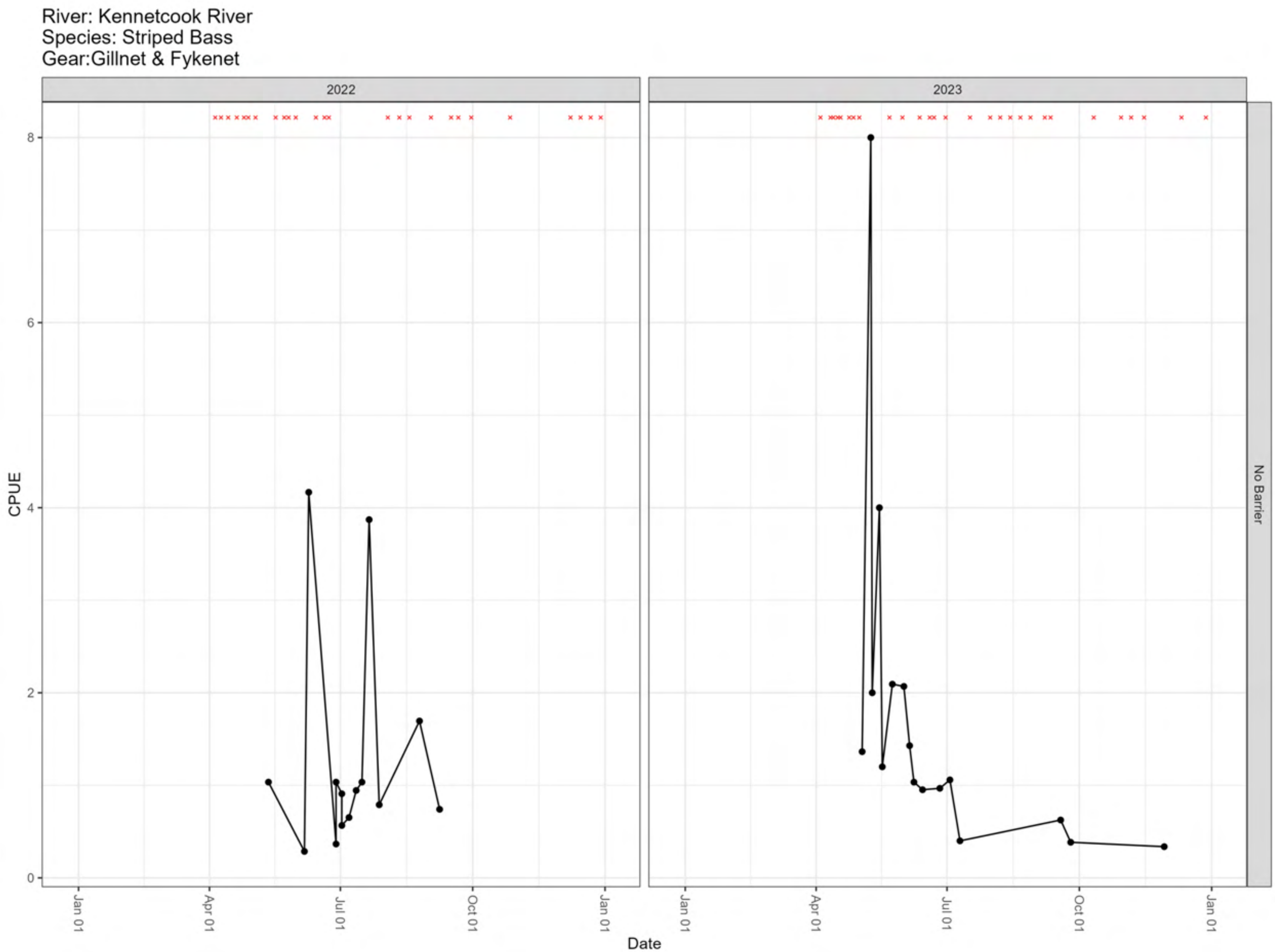
River: Kennetcook River
Species: Green Crab
Gear:Eel Trap & Minnow
2022
2023
No Barrier
CPUE
0
1
2
3
4
5
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01
Date

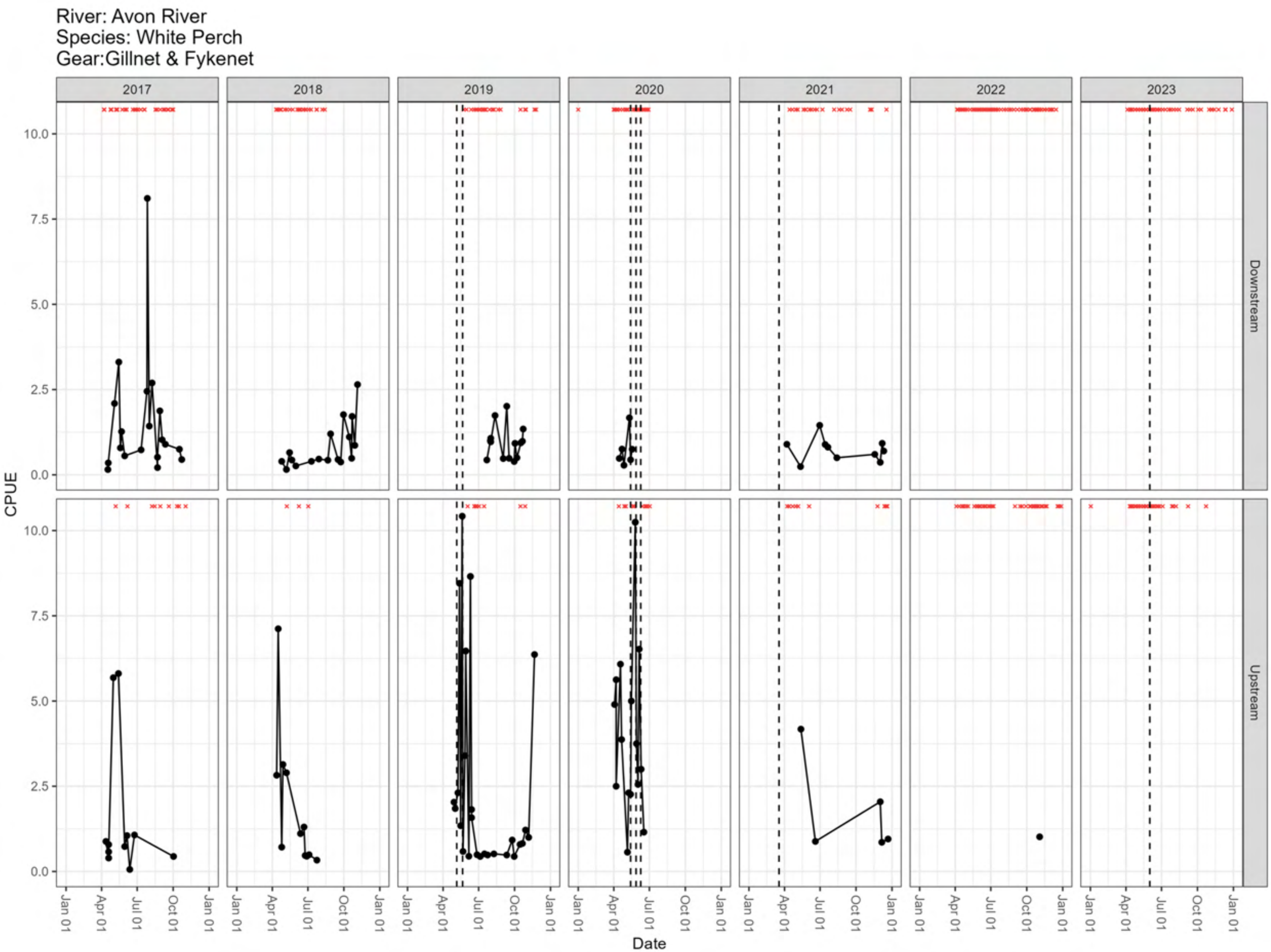

River: Avon River
Species: Rainbow Smelt
Gear:Gillnet & Fykenet
2017
2018
2019
2020
2021
2022
2023
Downstream
Upstream
CPUE
0
5
10
Jan 01
Apr 01
Jul 01
Oct 01
Date



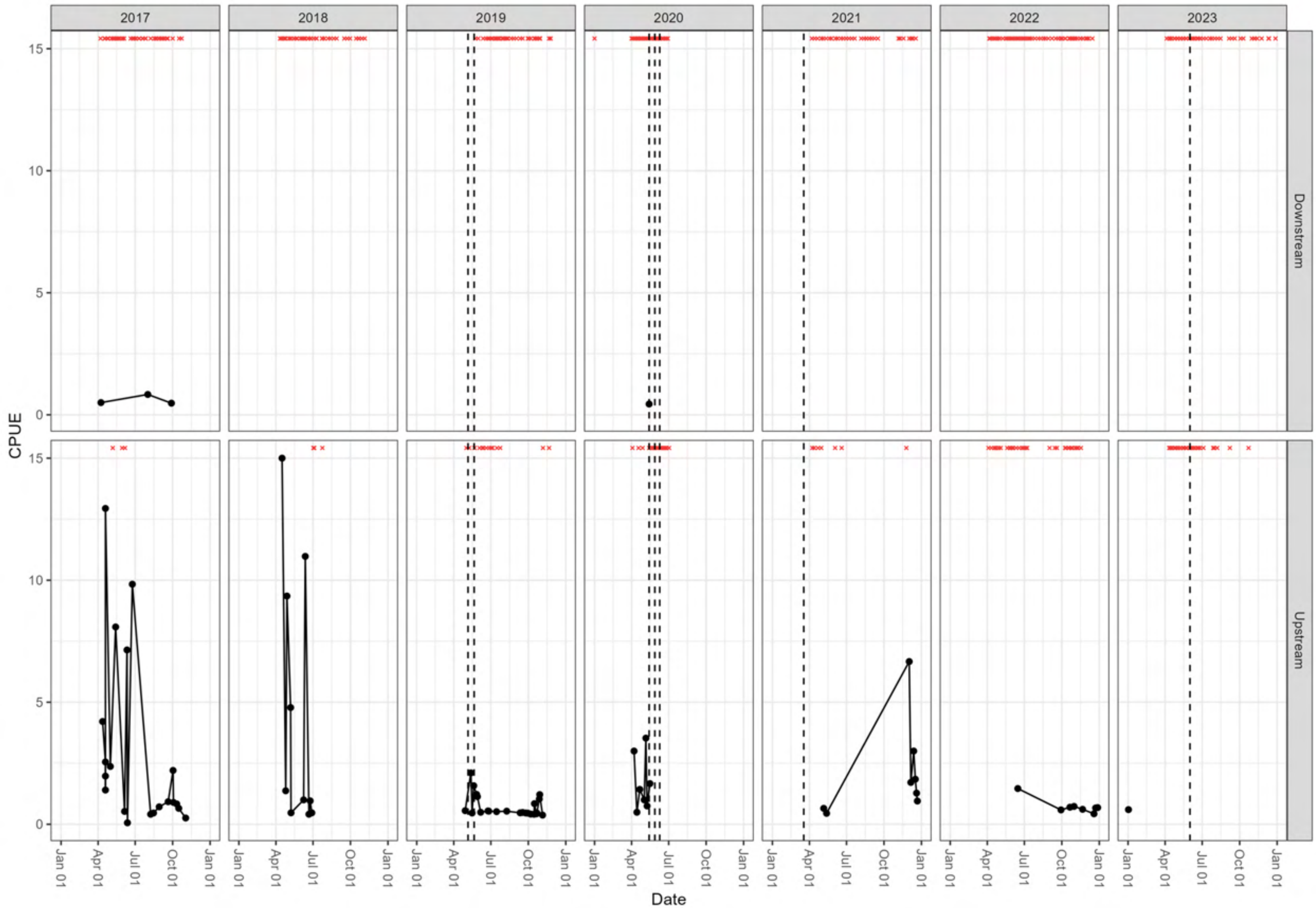
River: Kennetcook River
Species: Rainbow Smelt
Gear:Gillnet & Fykenet
2022
2023
No Barrier
CPUE
0.2
0.4
0.6
Date
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01


River: Avon River
Species: Striped Bass
Gear:Gillnet & Fykenet
2017
2018
2019
2020
2021
2022
2023
Downstream
Upstream
CPUE
0
10
20
30
Jan 01
Apr 01
Jul 01
Oct 01
Date


River: Kennetcook River
Species: Striped Bass
Gear:Gillnet & Fykenet
2022
2023
No Barrier
CPUE
0
2
4
6
8
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01
Jan 01
Apr 01
Jul 01
Oct 01
Jan 01
Date


River: Avon River
Species: White Perch
Gear:Gillnet & Fykenet
2017
2018
2019
2020
2021
2022
2023
Downstream
Upstream
CPUE
0.0
2.5
5.0
7.5
10.0
Jan 01
Apr 01
Jul 01
Oct 01
Date

River: Avon River
Species: White Sucker
Gear:Gillnet & Fykenet

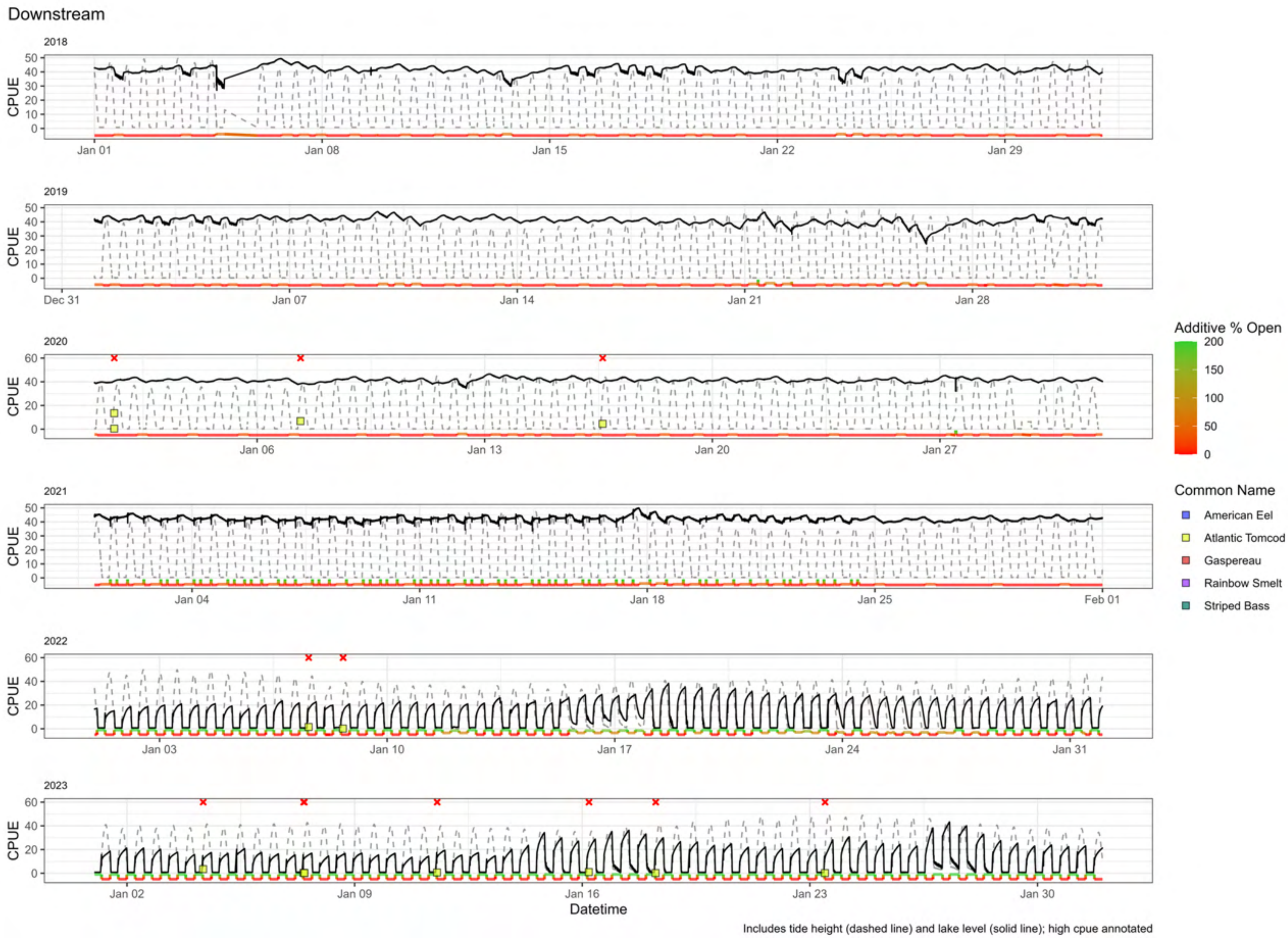


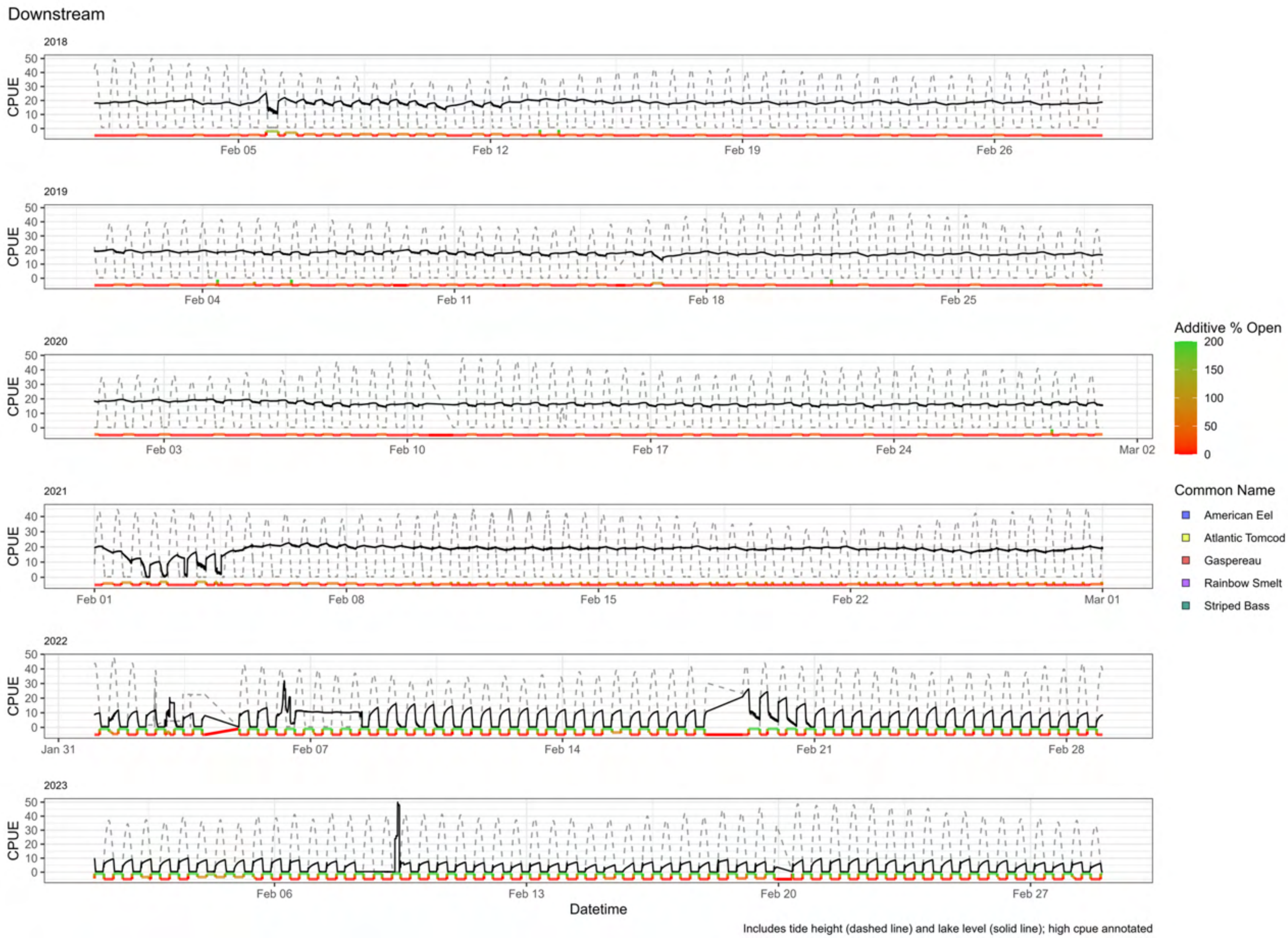
Appendix B - CPUE With Gate Operations and Water Levels

Red x's indicate dates when fishing events occurred.

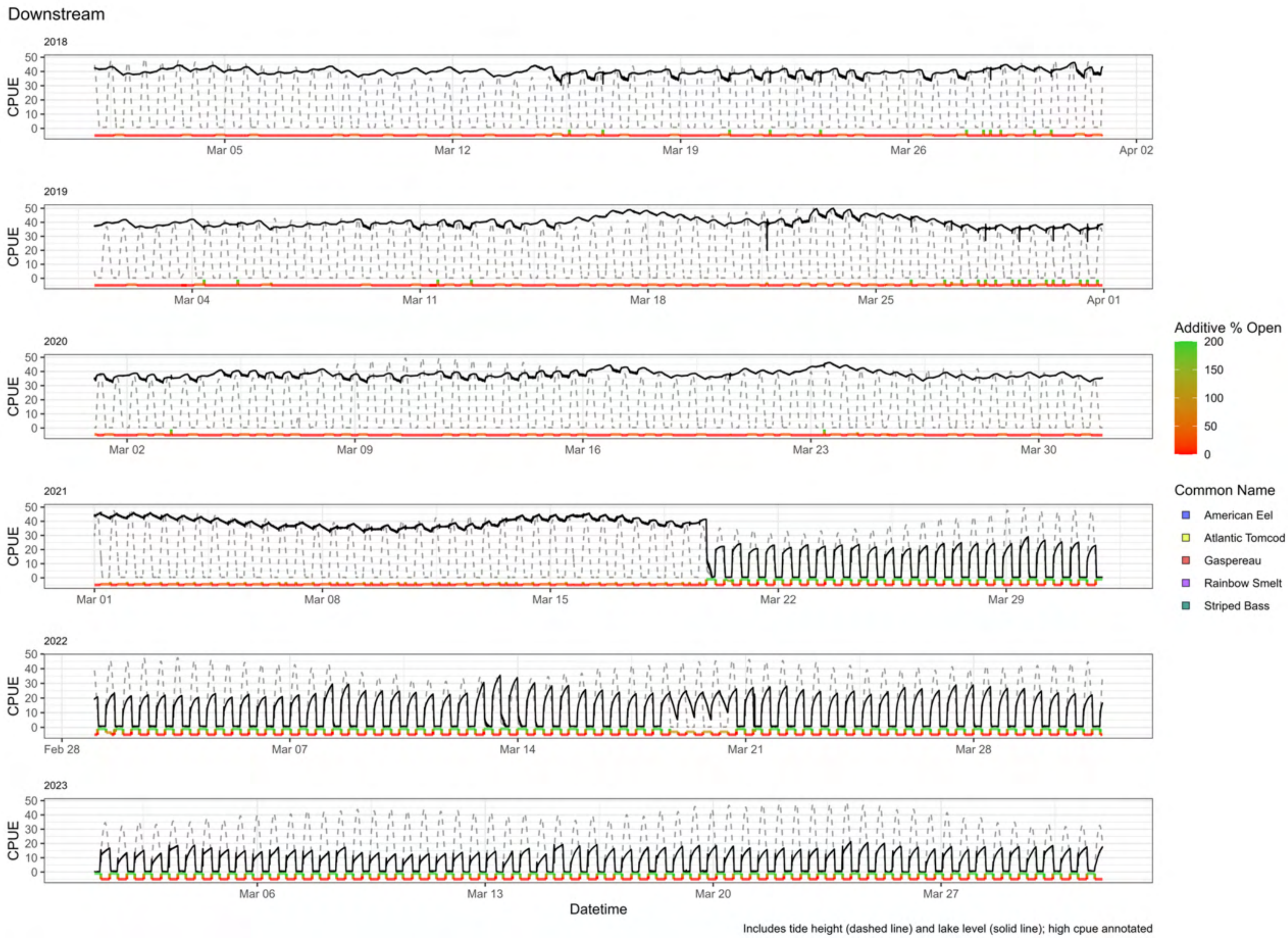
The CPUE for each set is reported individually. Occurrences where multiple CPUE values are reported for the same species for the same fishing event are a result of fishing gear being set multiple times during that survey.

Additive % opening refers to degree to which causeway gates are open. Zero % (red) is both gates fully shut, 100% equates to one gate fully open and one gate fully shut (yellow) and 200% equates to both gates fully open (green).

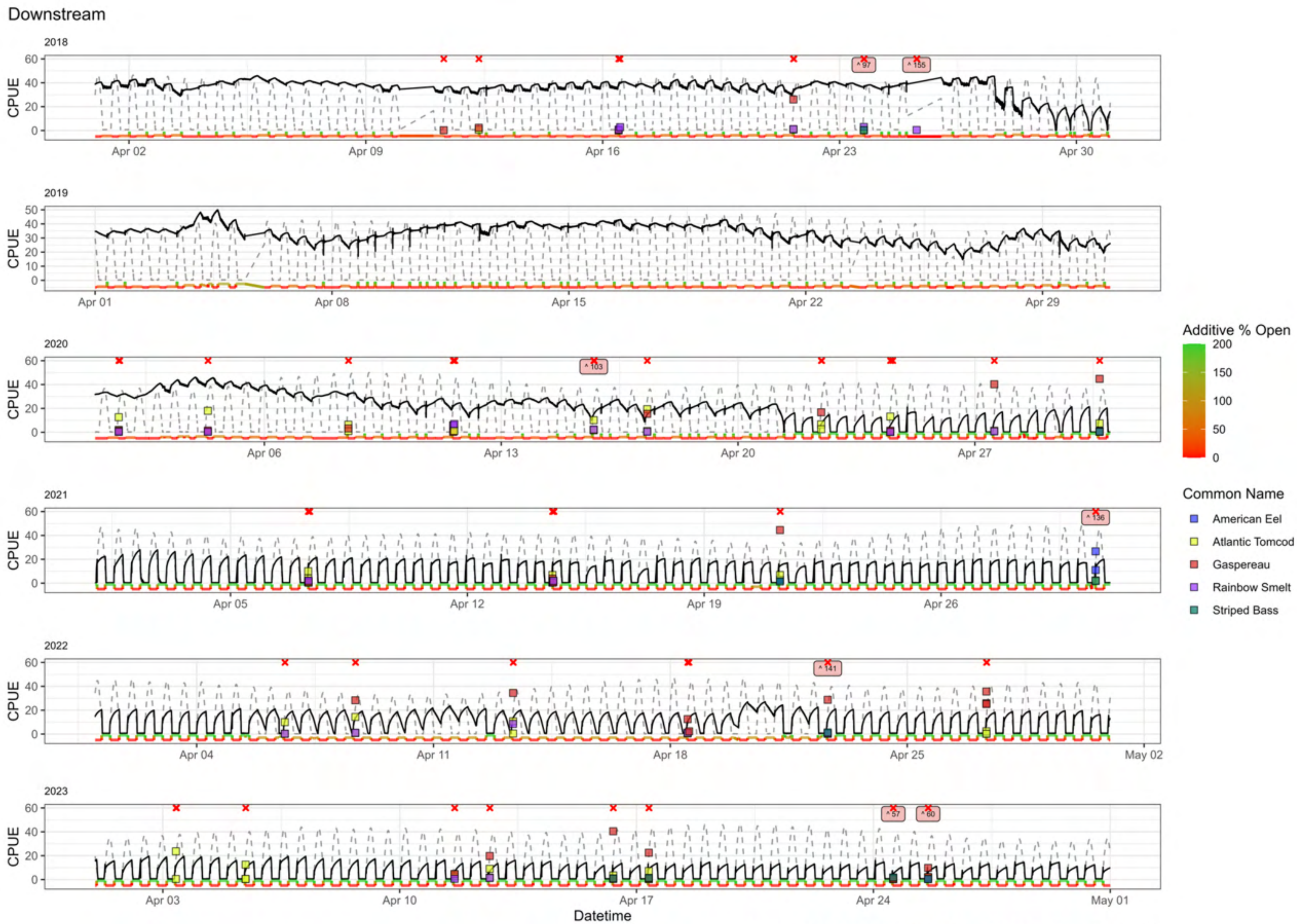

Downstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated



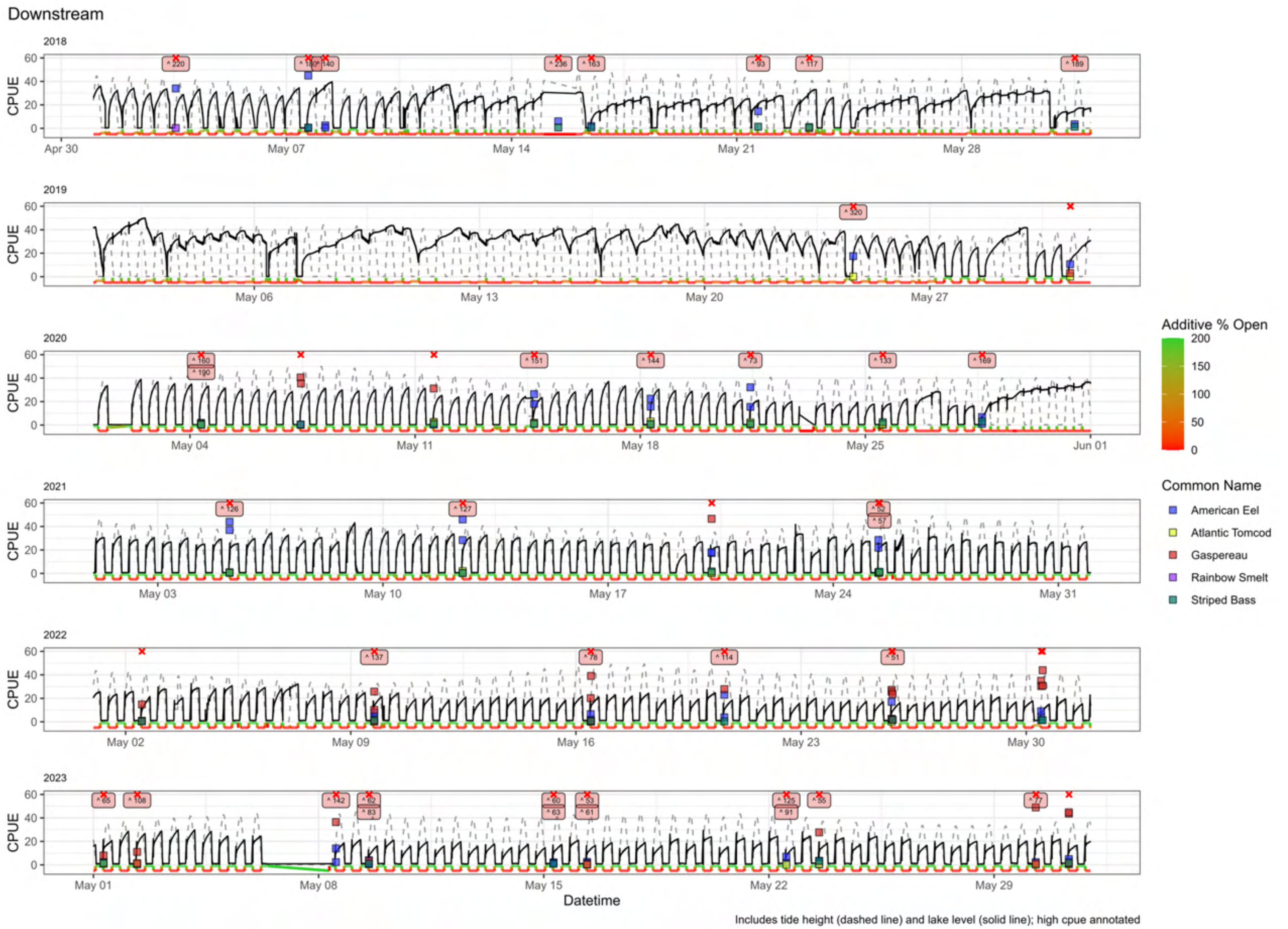
Downstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

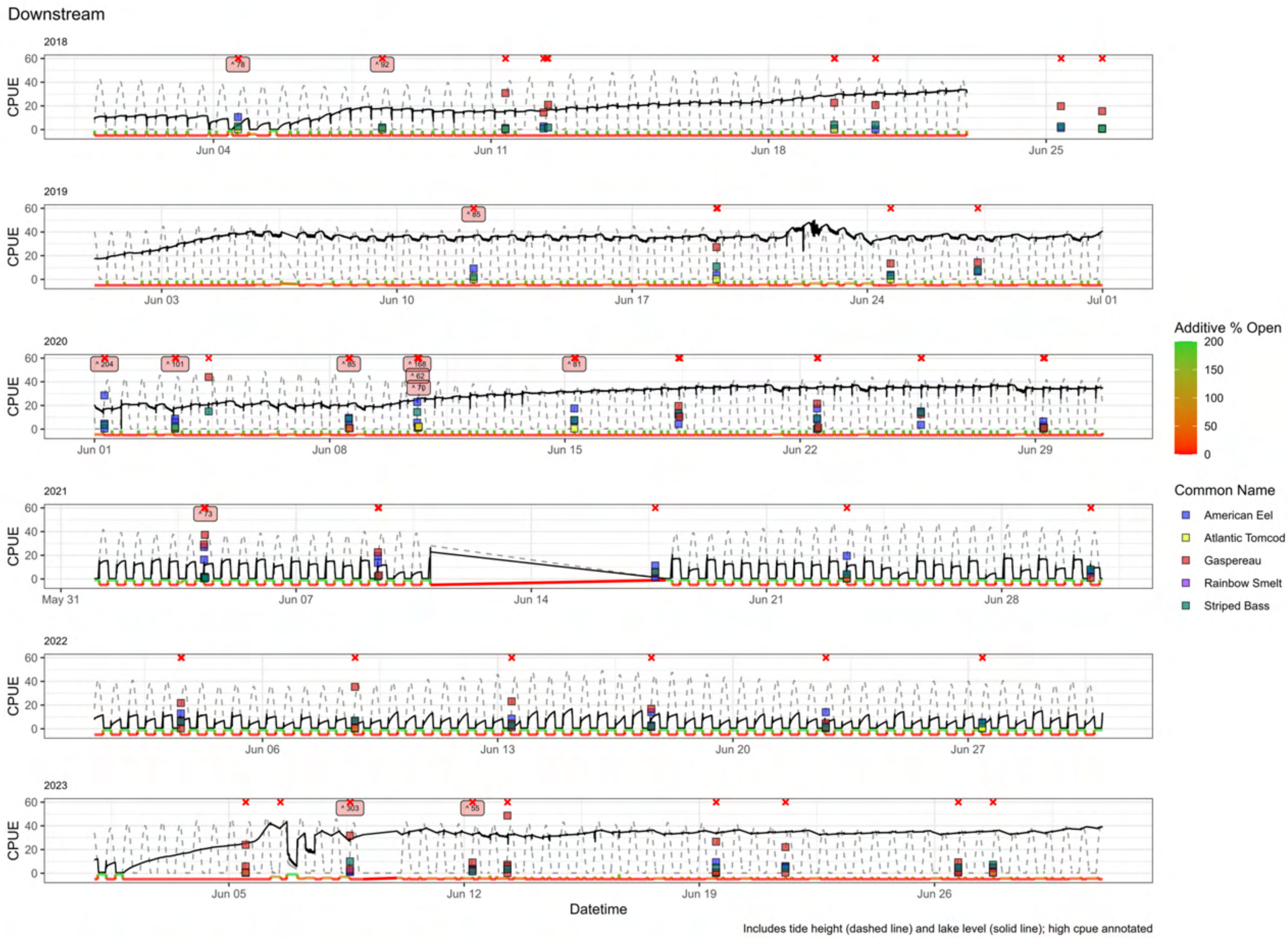


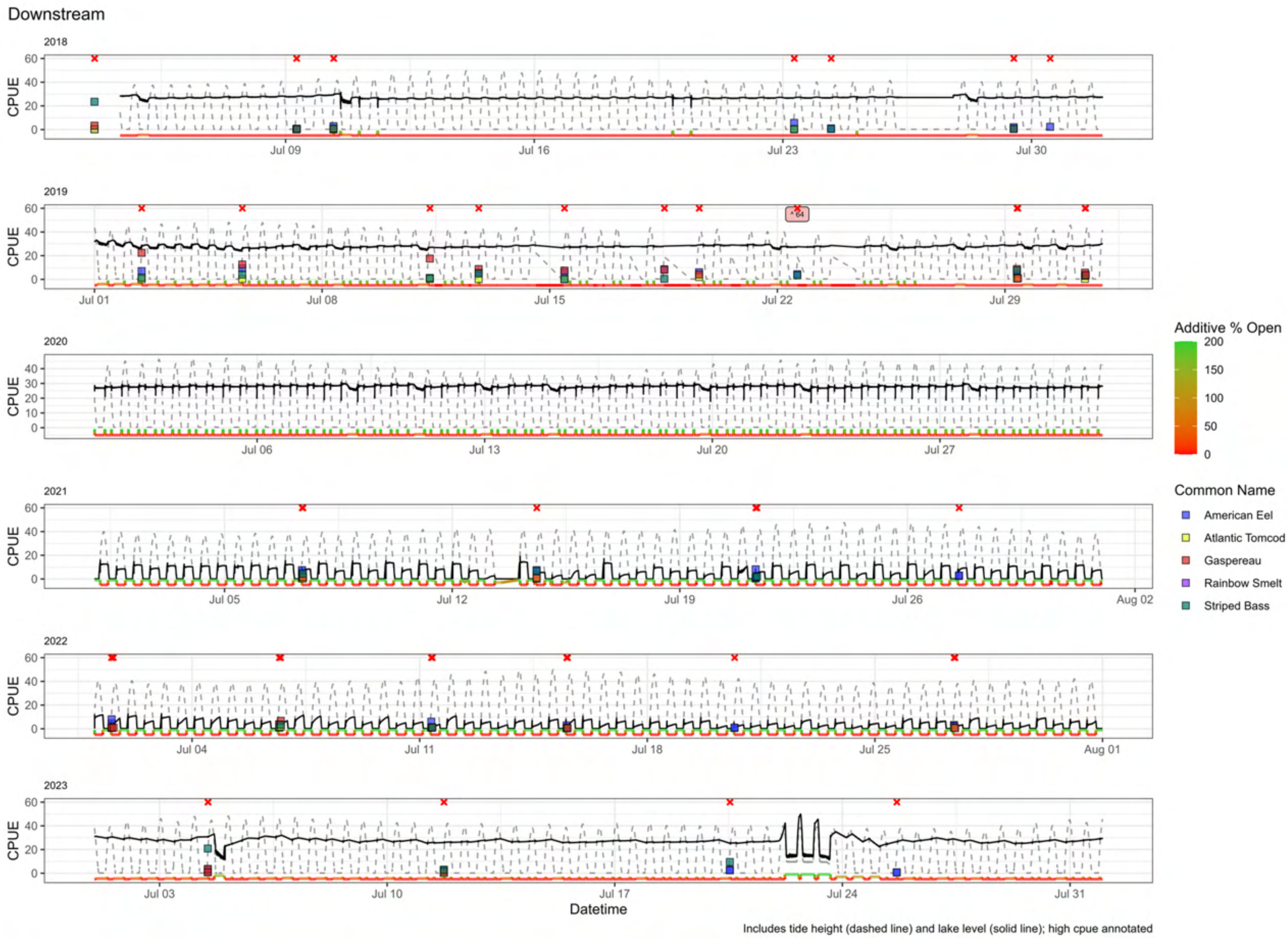
Downstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated



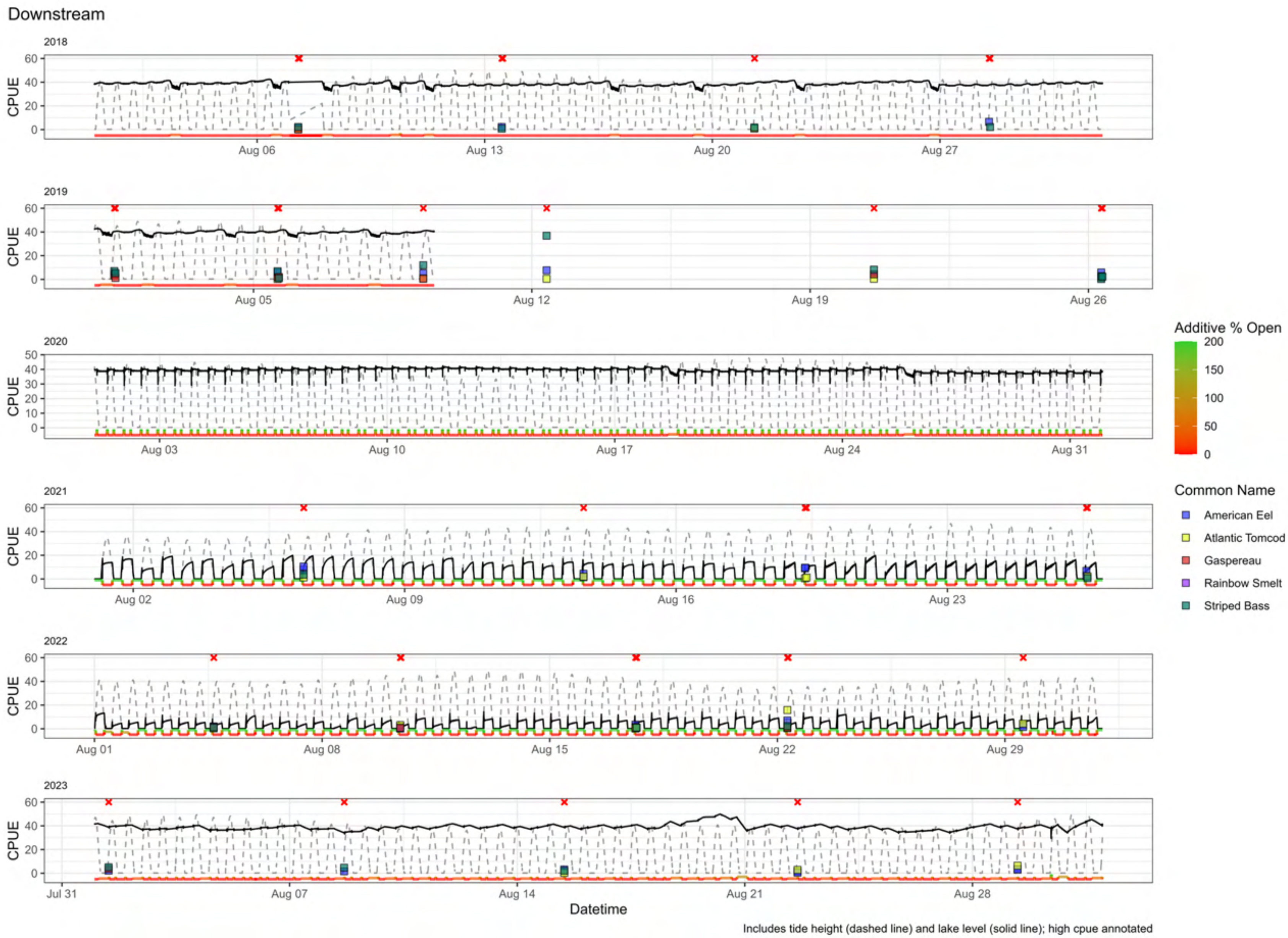
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

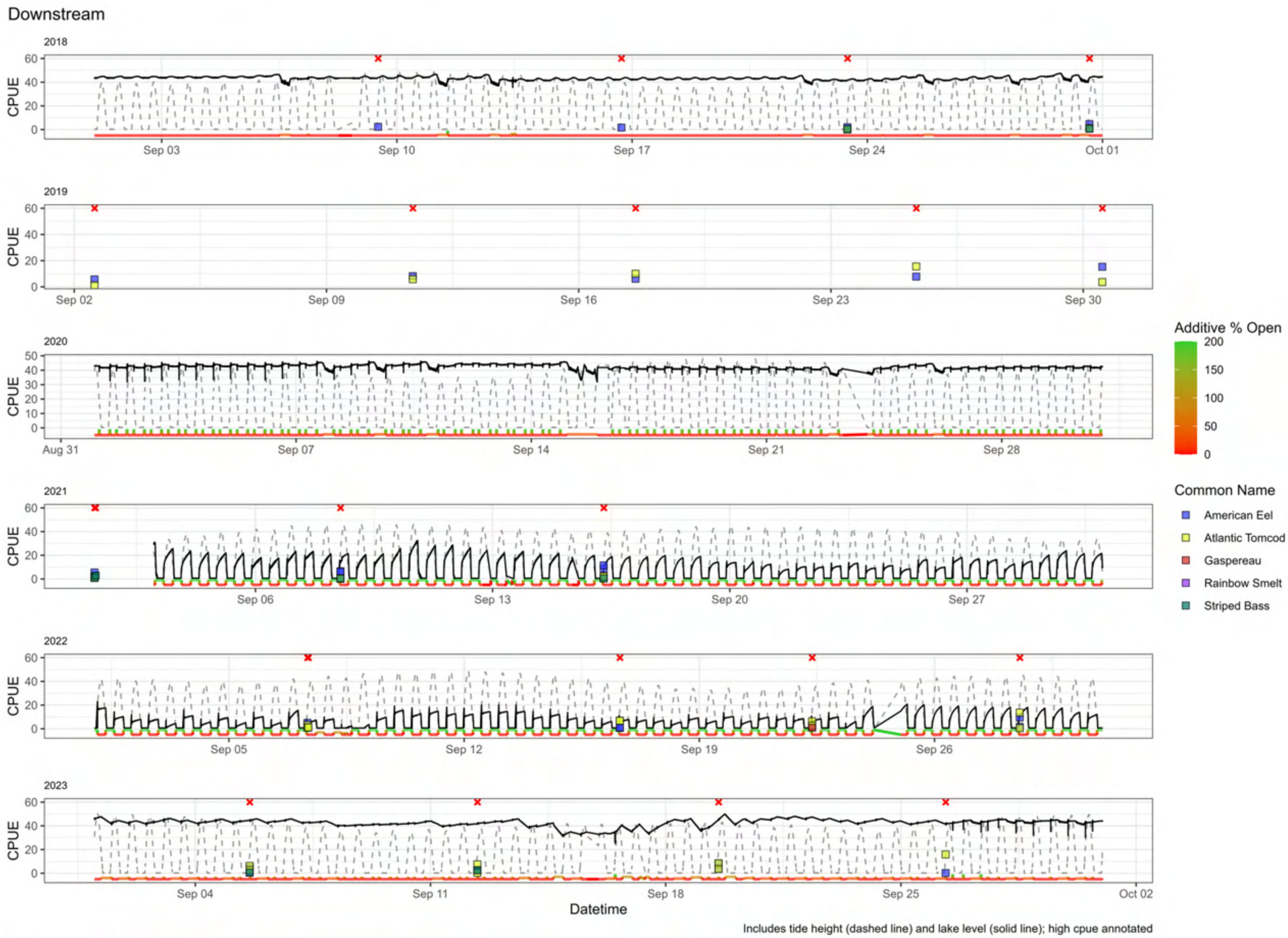

Downstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated


Downstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

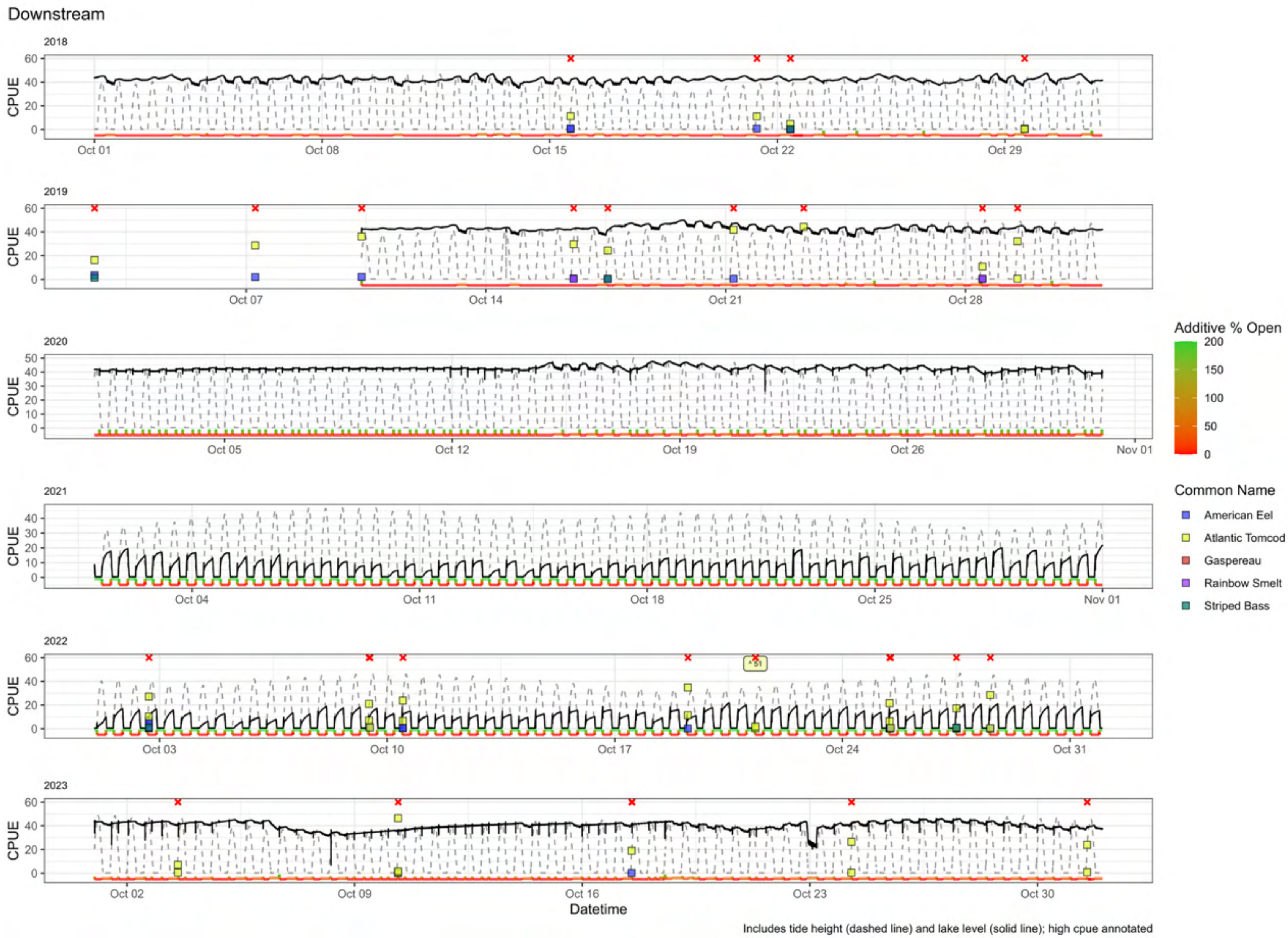


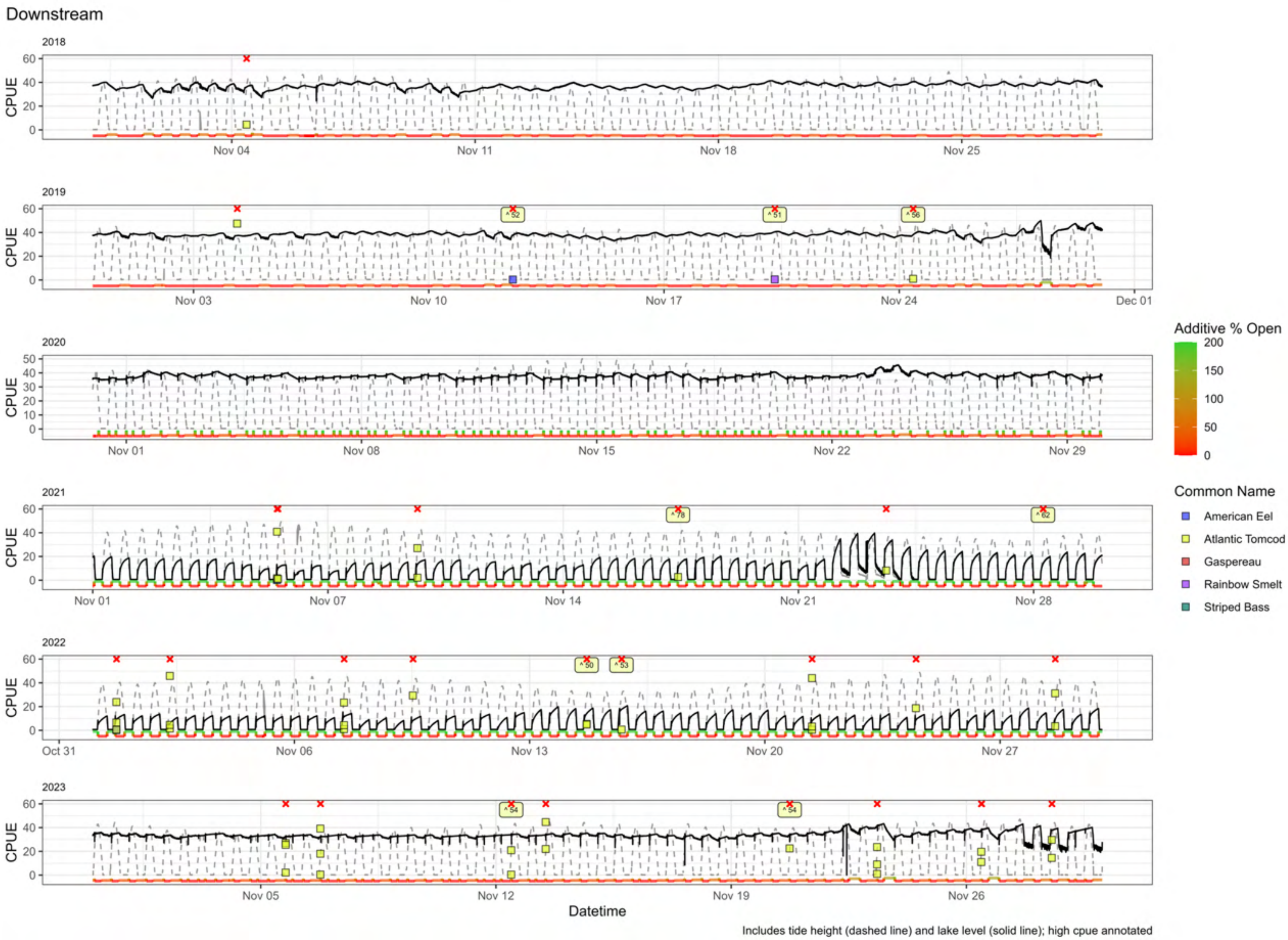
Downstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
^64
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated


Downstream
2018
2019
2020
2021
2022
2023
CPUE
Aug 06
Aug 13
Aug 20
Aug 27
Aug 05
Aug 12
Aug 19
Aug 26
Aug 03
Aug 10
Aug 17
Aug 24
Aug 31
Aug 02
Aug 09
Aug 16
Aug 23
Aug 01
Aug 08
Aug 15
Aug 22
Aug 29
Jul 31
Aug 07
Aug 14
Aug 21
Aug 28
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

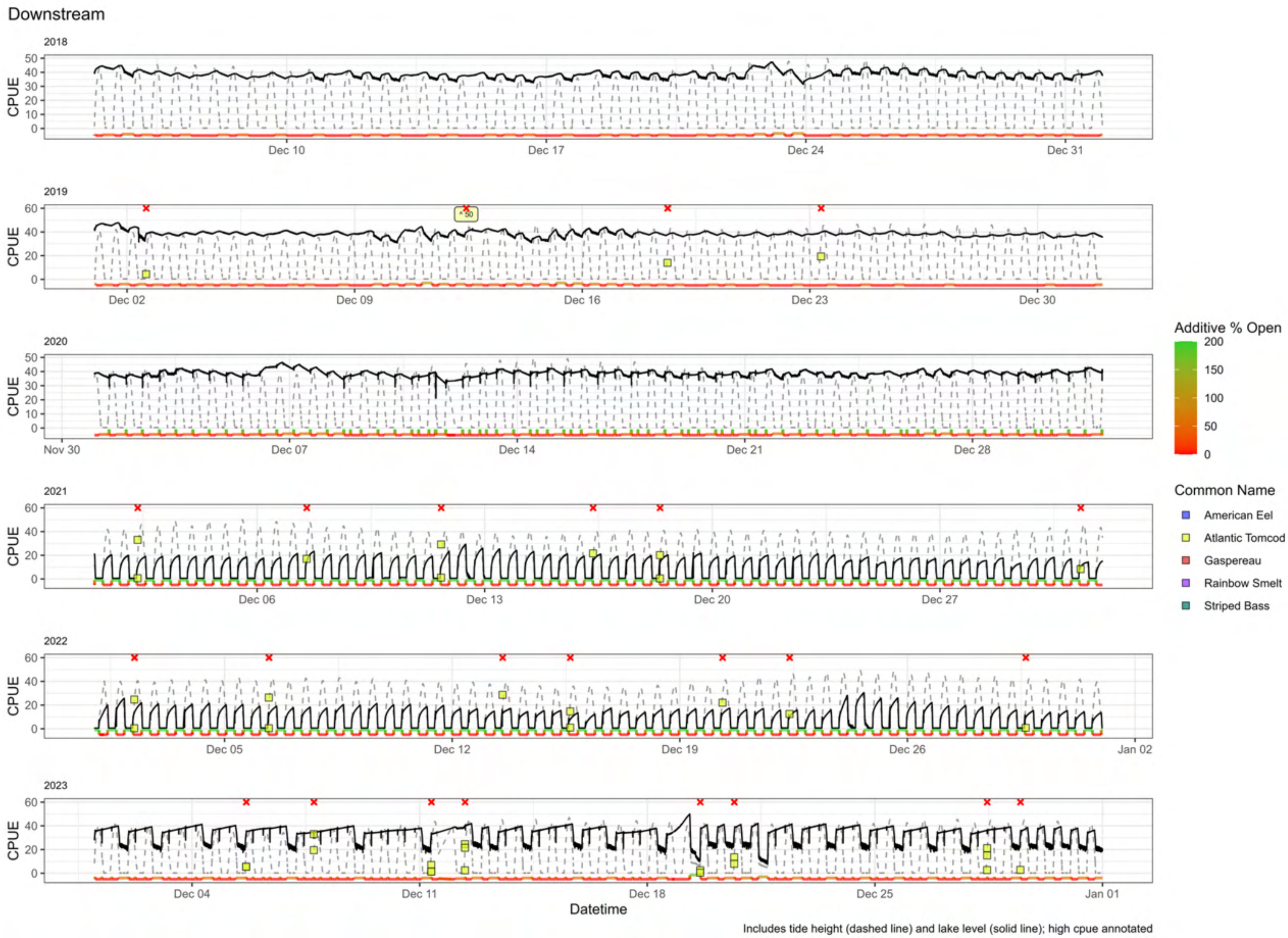


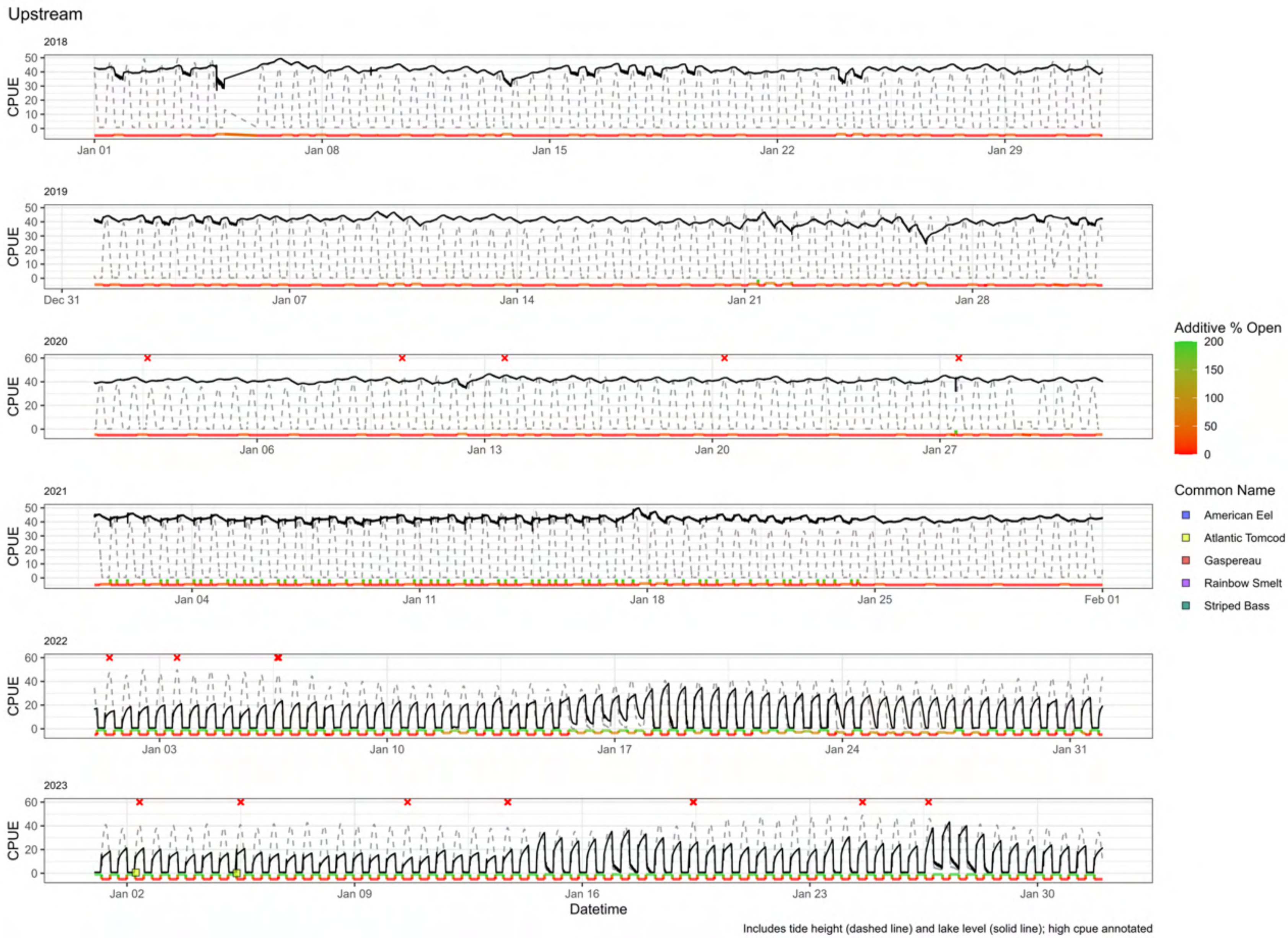
Downstream
2018
2019
2020
2021
2022
2023
CPUE
Sep 03
Sep 10
Sep 17
Sep 24
Oct 01
Sep 02
Sep 09
Sep 16
Sep 23
Sep 30
Aug 31
Sep 07
Sep 14
Sep 21
Sep 28
Sep 06
Sep 13
Sep 20
Sep 27
Sep 05
Sep 12
Sep 19
Sep 26
Sep 04
Sep 11
Sep 18
Sep 25
Oct 02
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

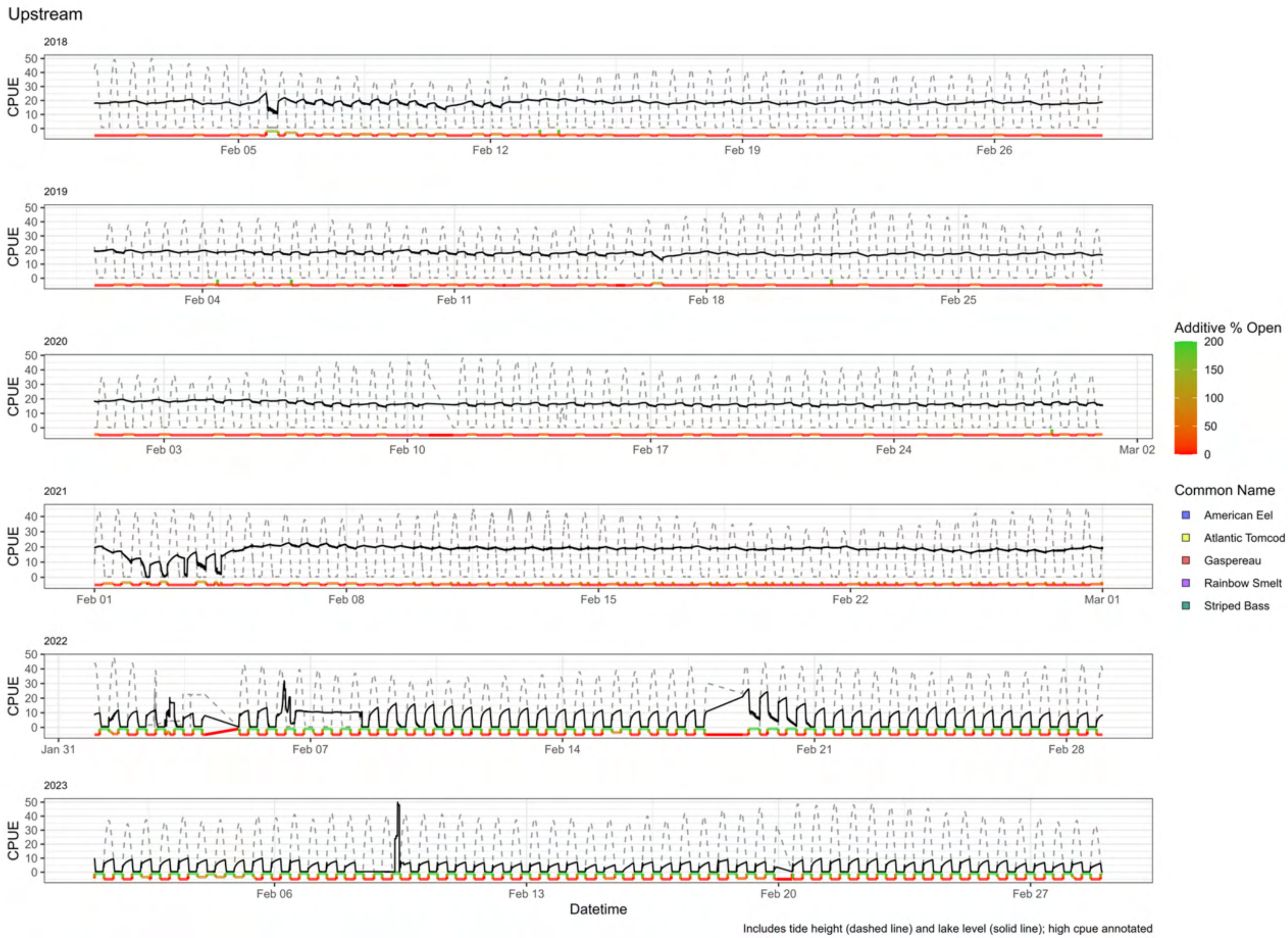

Downstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

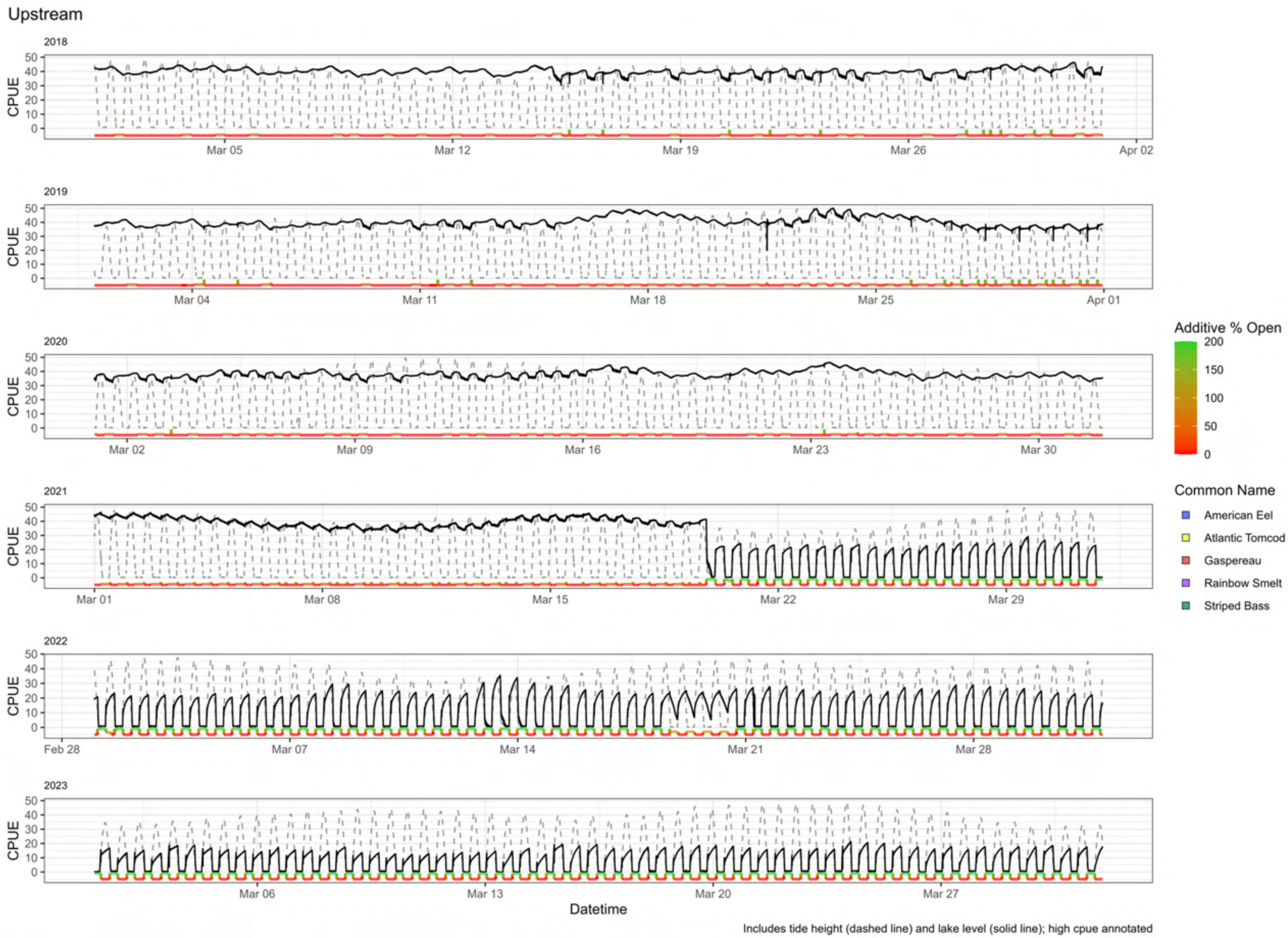


Downstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

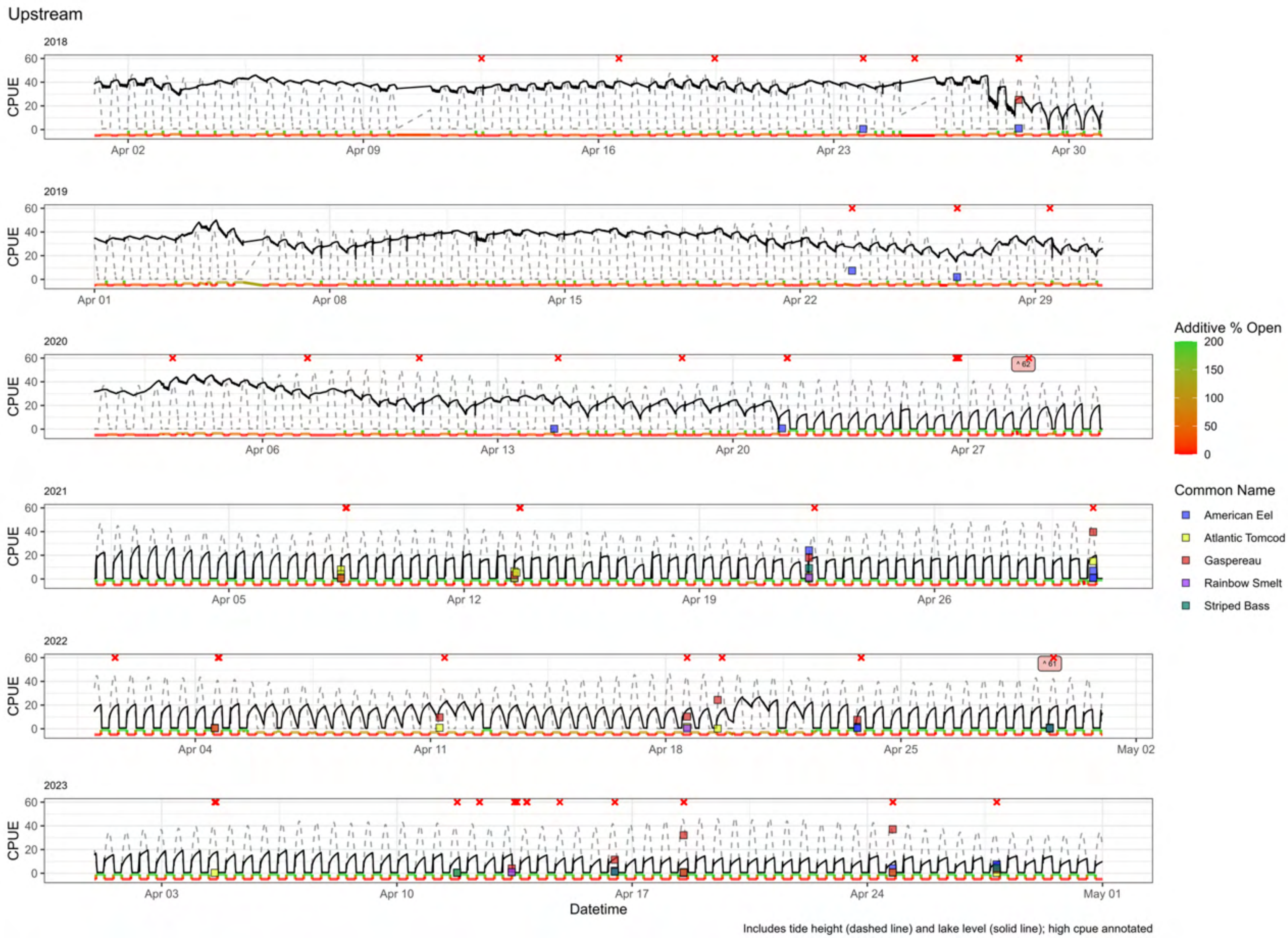

Downstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

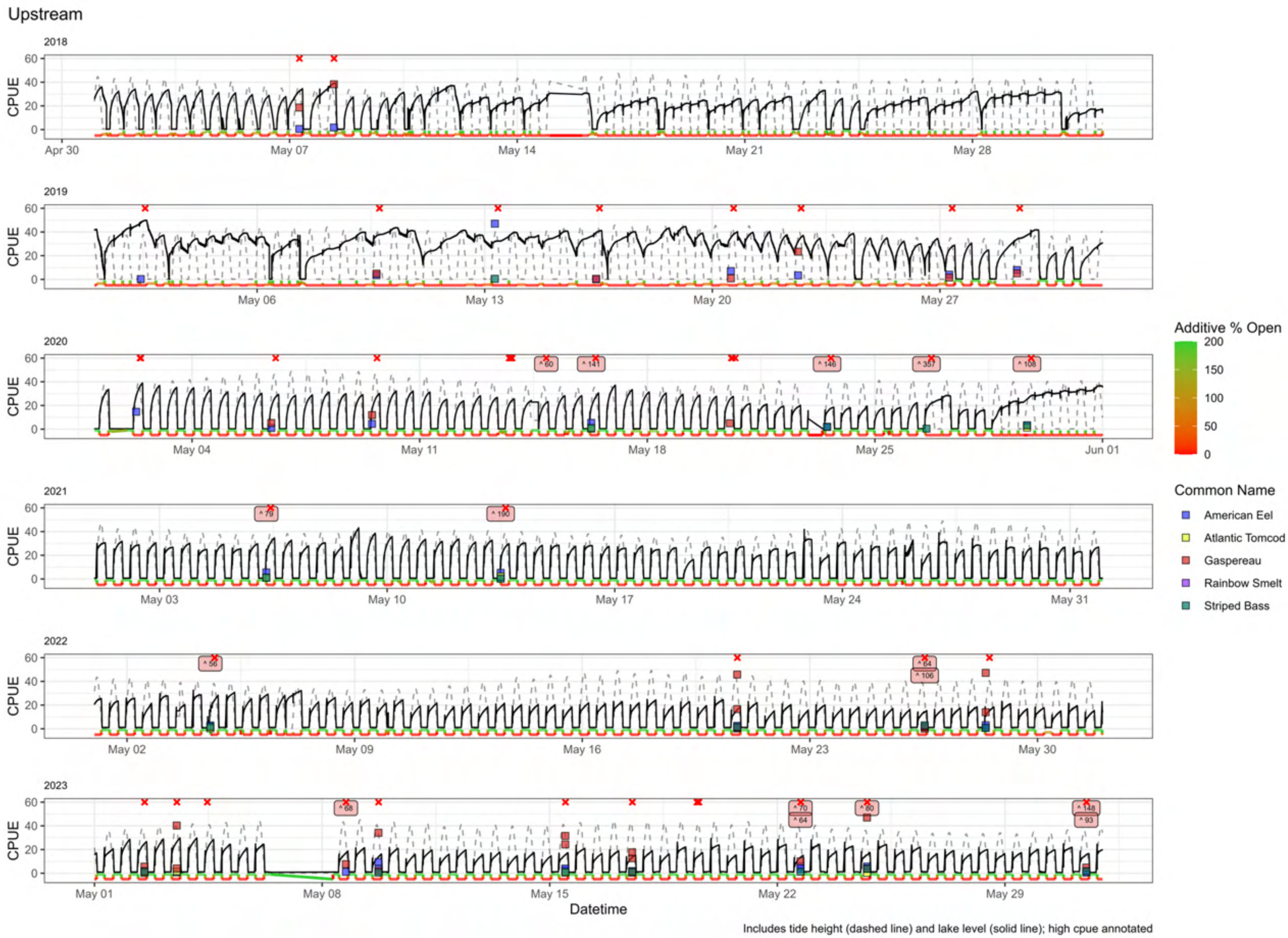

Upstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

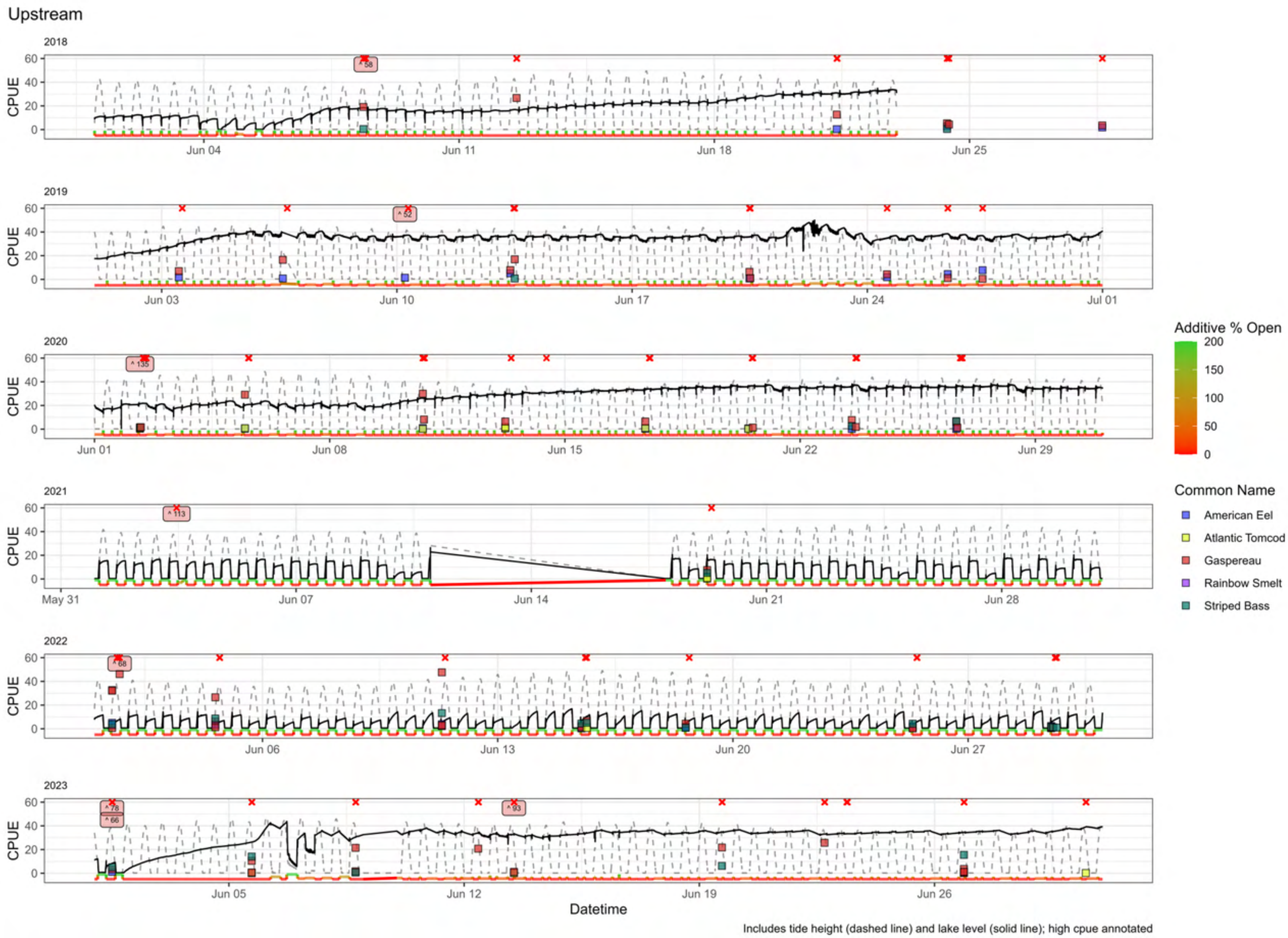

Upstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

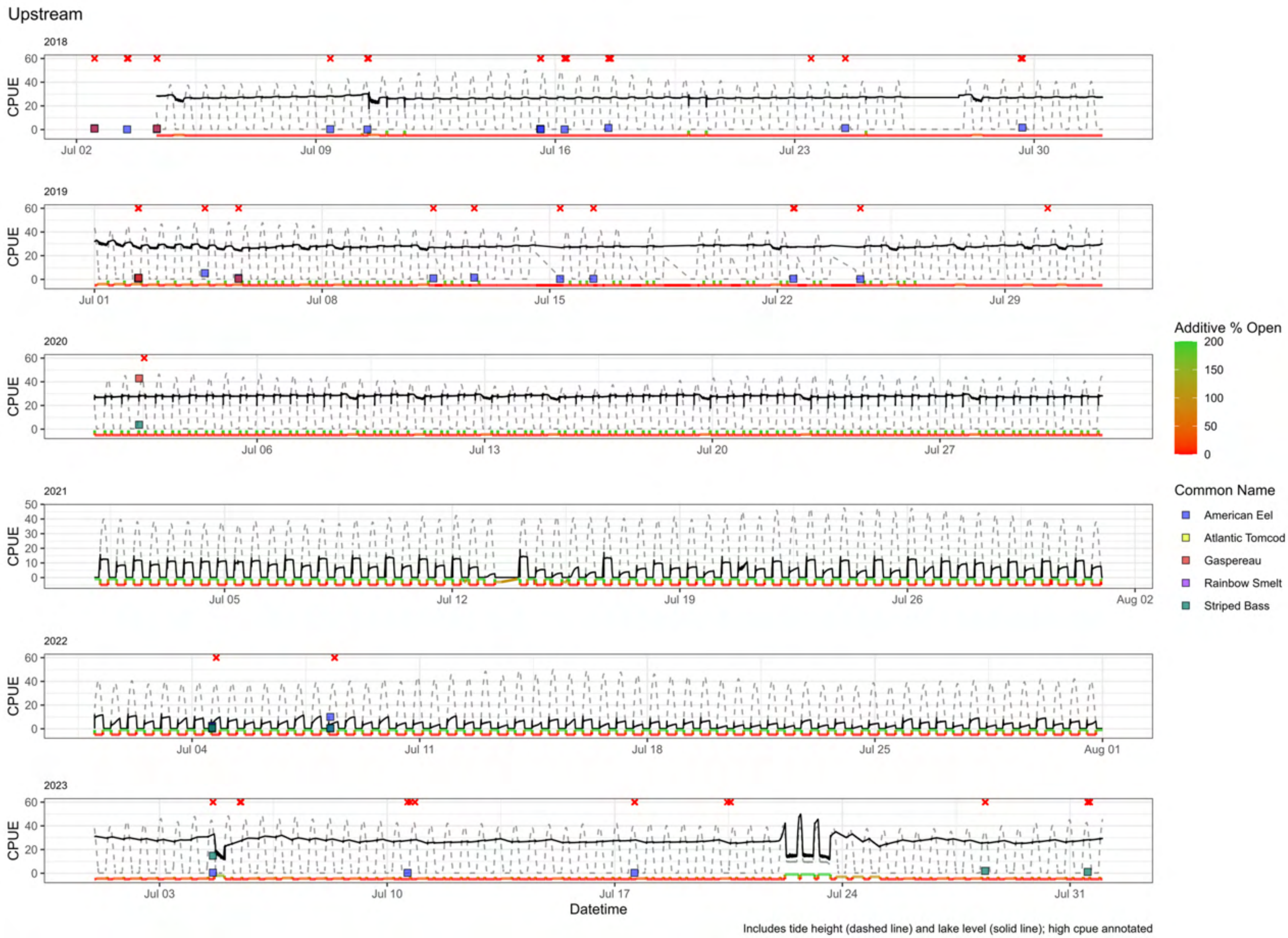


Upstream
2018
2019
2020
2021
2022
2023
CPUE
0
10
20
30
40
50
Mar 05
Mar 12
Mar 19
Mar 26
Apr 02
Mar 04
Mar 11
Mar 18
Mar 25
Apr 01
Mar 02
Mar 09
Mar 16
Mar 23
Mar 30
Mar 01
Mar 08
Mar 15
Mar 22
Mar 29
Feb 28
Mar 07
Mar 14
Mar 21
Mar 28
Mar 06
Mar 13
Mar 20
Mar 27
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

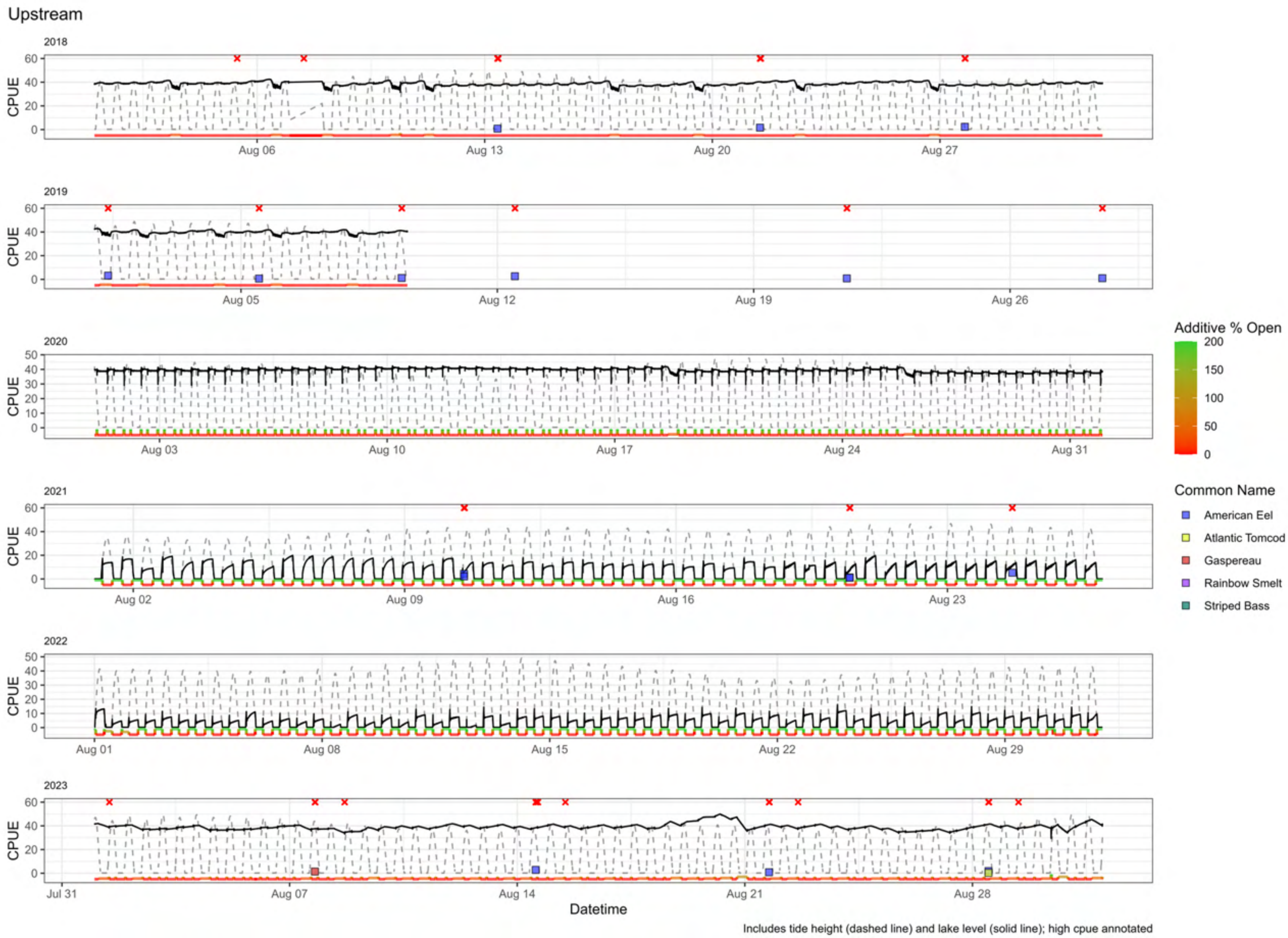

Upstream
2018
2019
2020
2021
2022
2023
CPUE
60
40
20
0
Apr 02
Apr 09
Apr 16
Apr 23
Apr 30
Apr 01
Apr 08
Apr 15
Apr 22
Apr 29
Apr 06
Apr 13
Apr 20
Apr 27
Apr 05
Apr 12
Apr 19
Apr 26
Apr 04
Apr 11
Apr 18
Apr 25
May 02
Apr 03
Apr 10
Apr 17
Apr 24
May 01
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

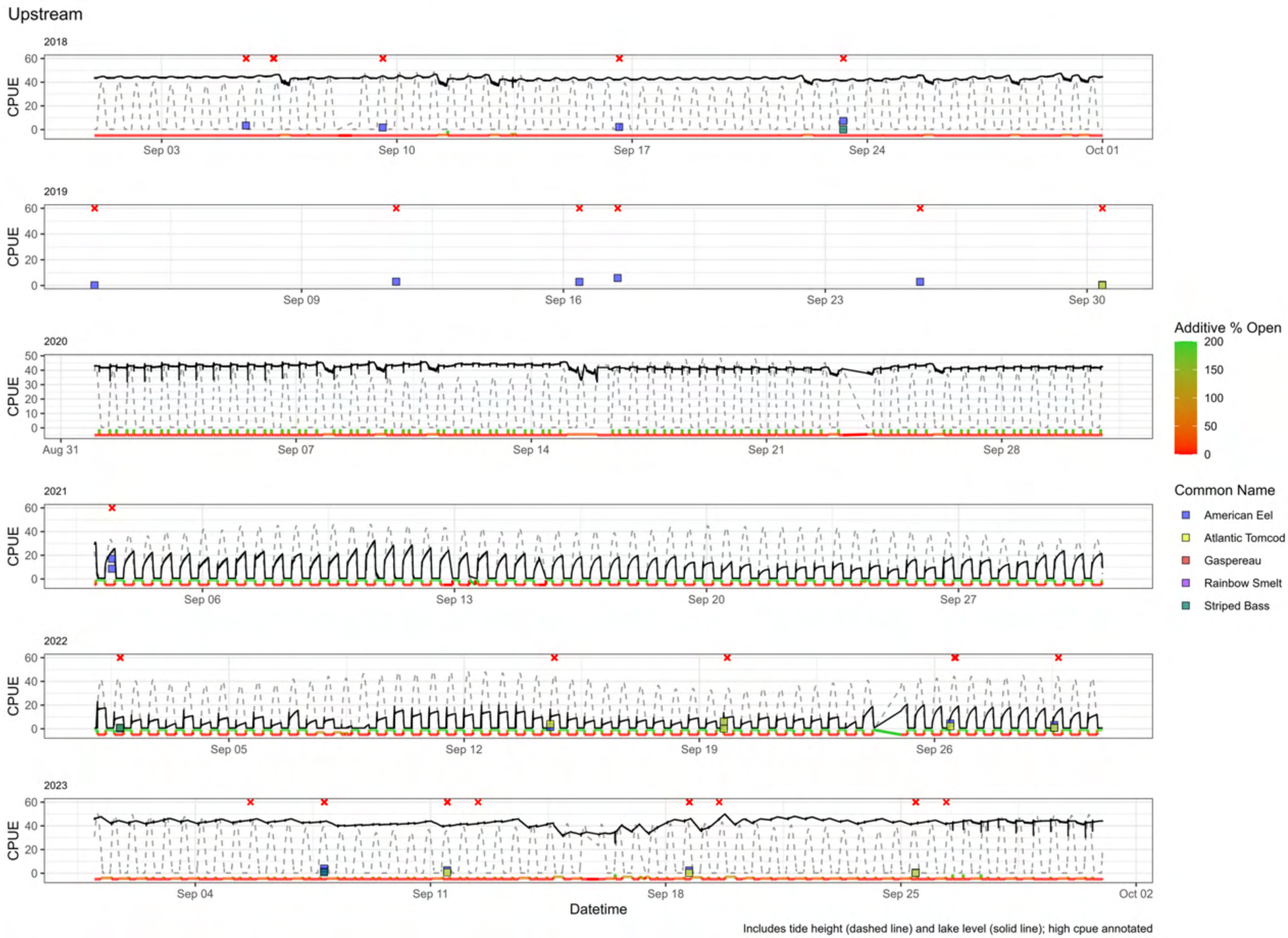

Upstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated


Upstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

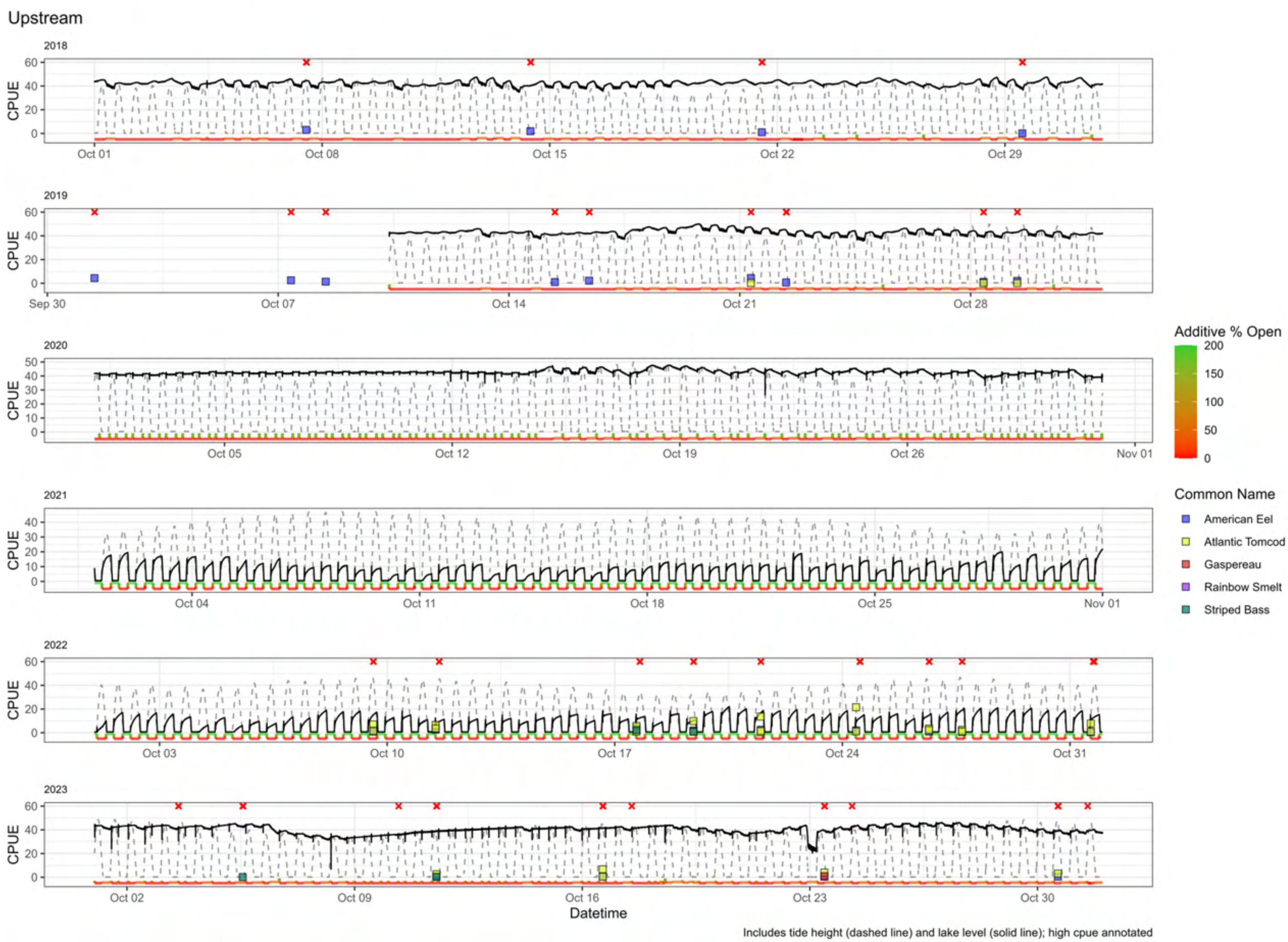


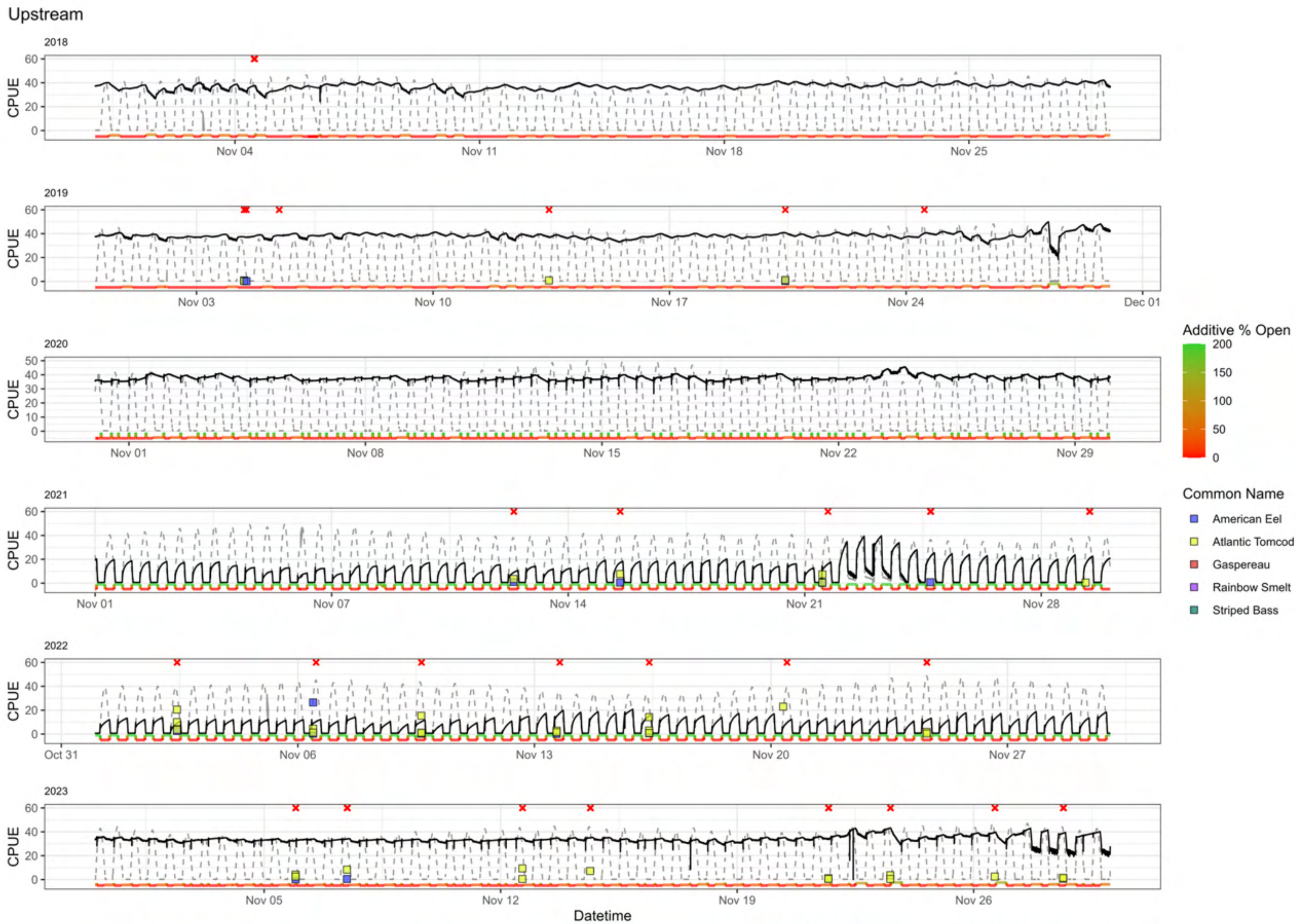
Upstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated


Upstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

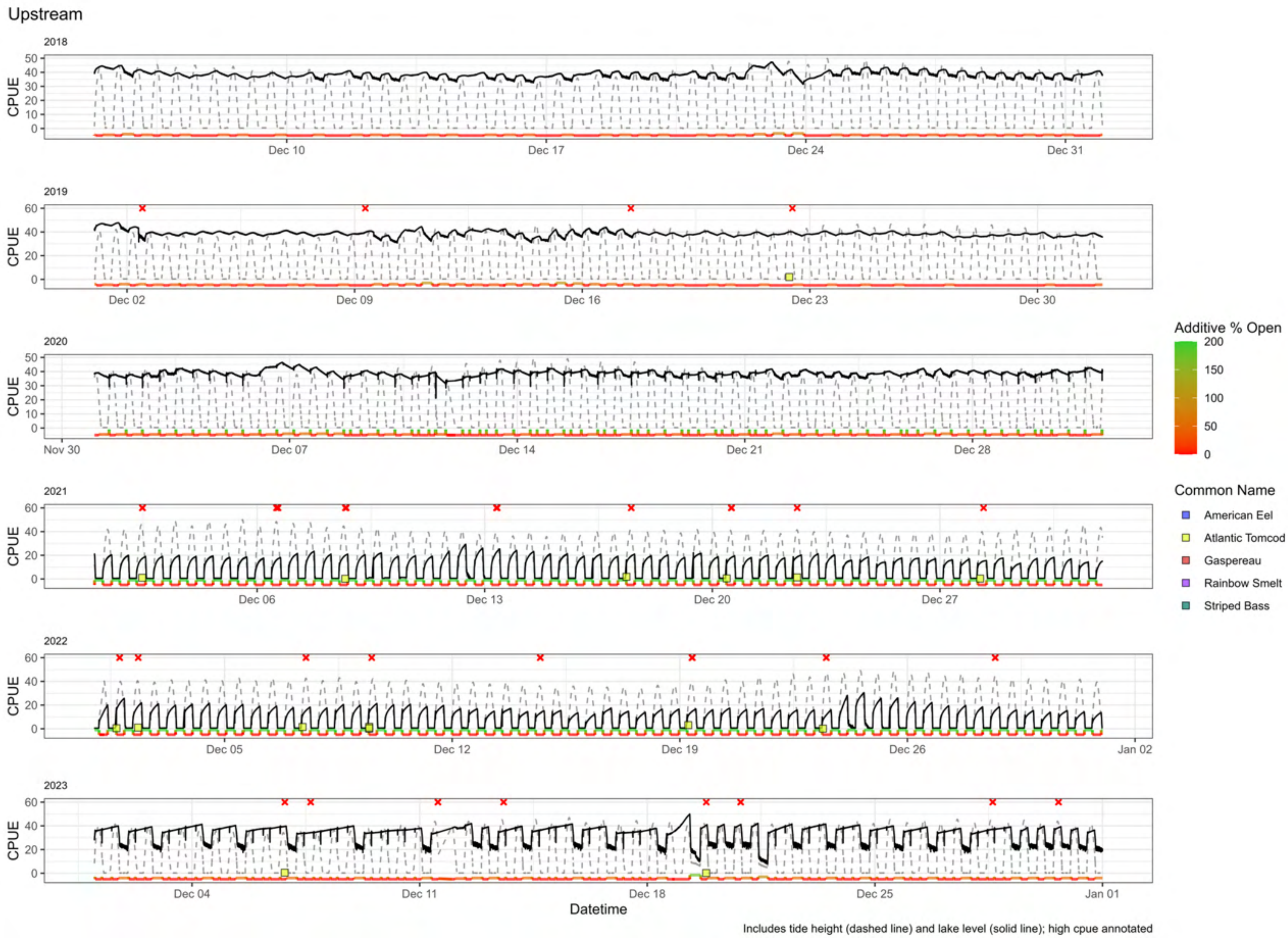


Upstream
2018
2019
2020
2021
2022
2023
CPUE
Sep 03
Sep 10
Sep 17
Sep 24
Oct 01
Sep 09
Sep 16
Sep 23
Sep 30
Aug 31
Sep 07
Sep 14
Sep 21
Sep 28
Sep 06
Sep 13
Sep 20
Sep 27
Sep 05
Sep 12
Sep 19
Sep 26
Sep 04
Sep 11
Sep 18
Sep 25
Oct 02
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated


Upstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
200
150
100
50
0
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated



Includes tide height (dashed line) and lake level (solid line); high cpue annotated


Upstream
2018
2019
2020
2021
2022
2023
CPUE
Datetime
Additive % Open
Common Name
American Eel
Atlantic Tomcod
Gaspereau
Rainbow Smelt
Striped Bass
Includes tide height (dashed line) and lake level (solid line); high cpue annotated

Appendix C – PIT and T-bar Tagging

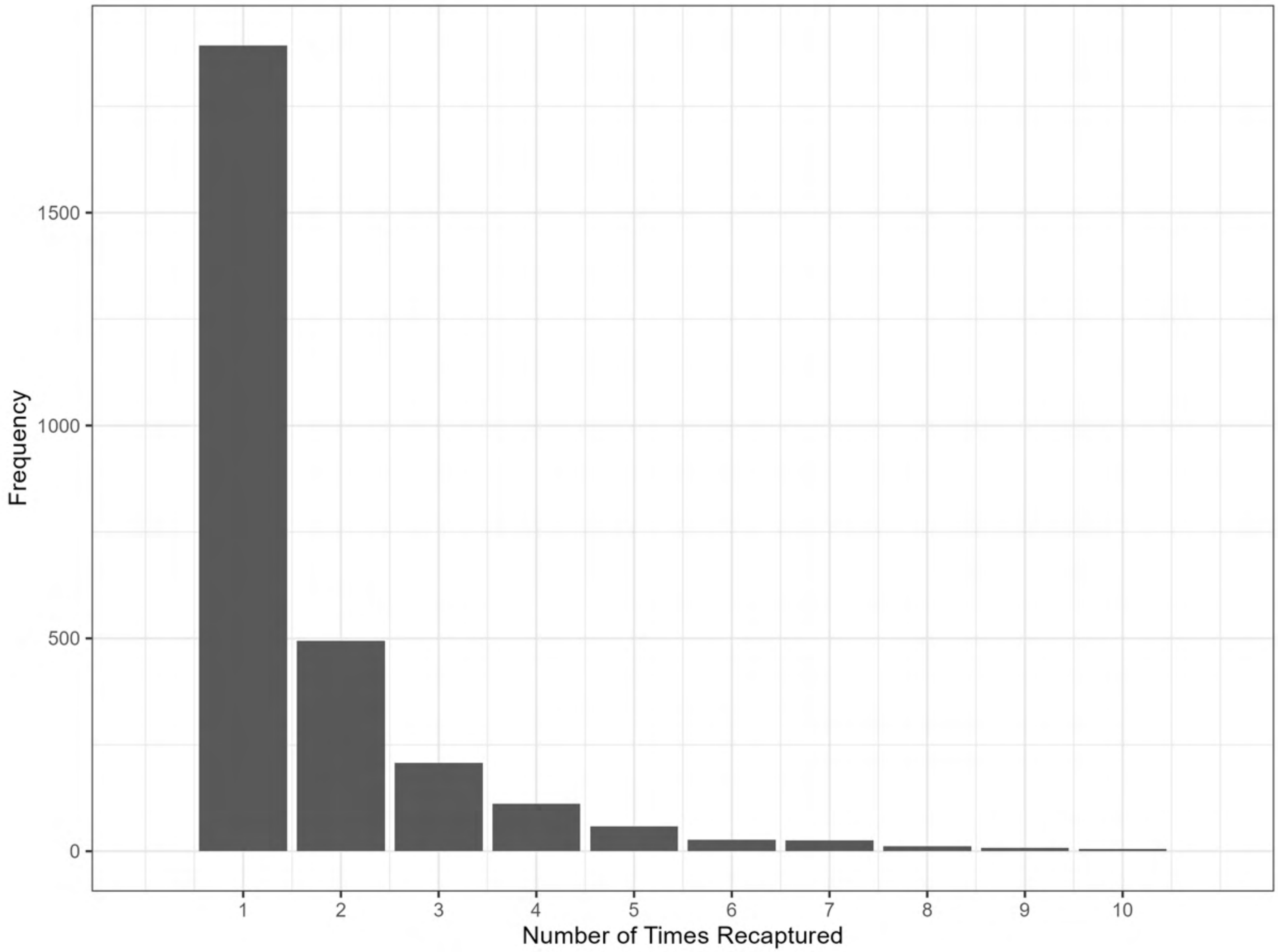


Figure 22 Recapture frequency of PIT tagged fish for all species at all monitoring sites.

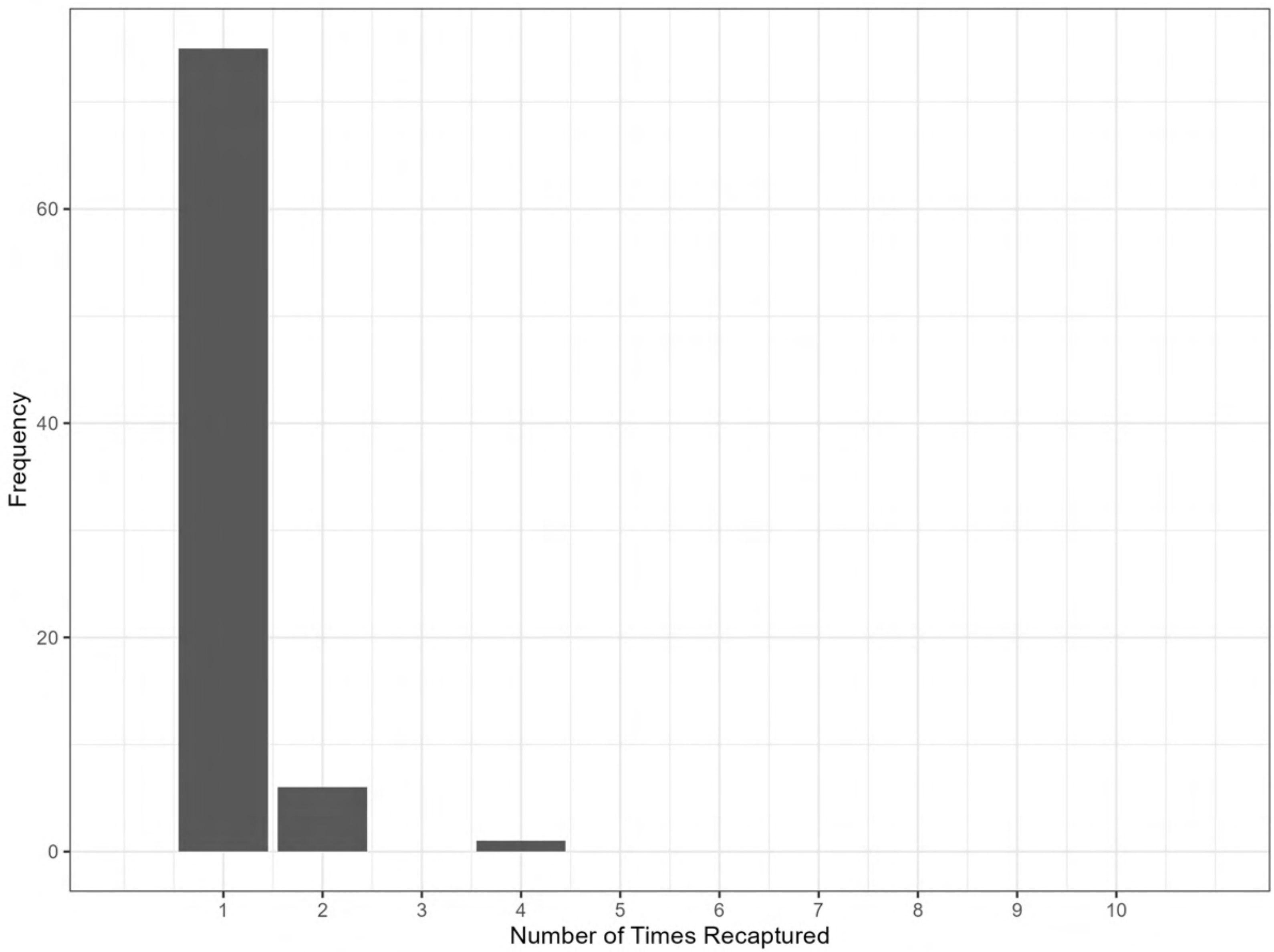


Figure 23 Recapture frequency of T-bar tagged fish for all species at all monitoring sites.

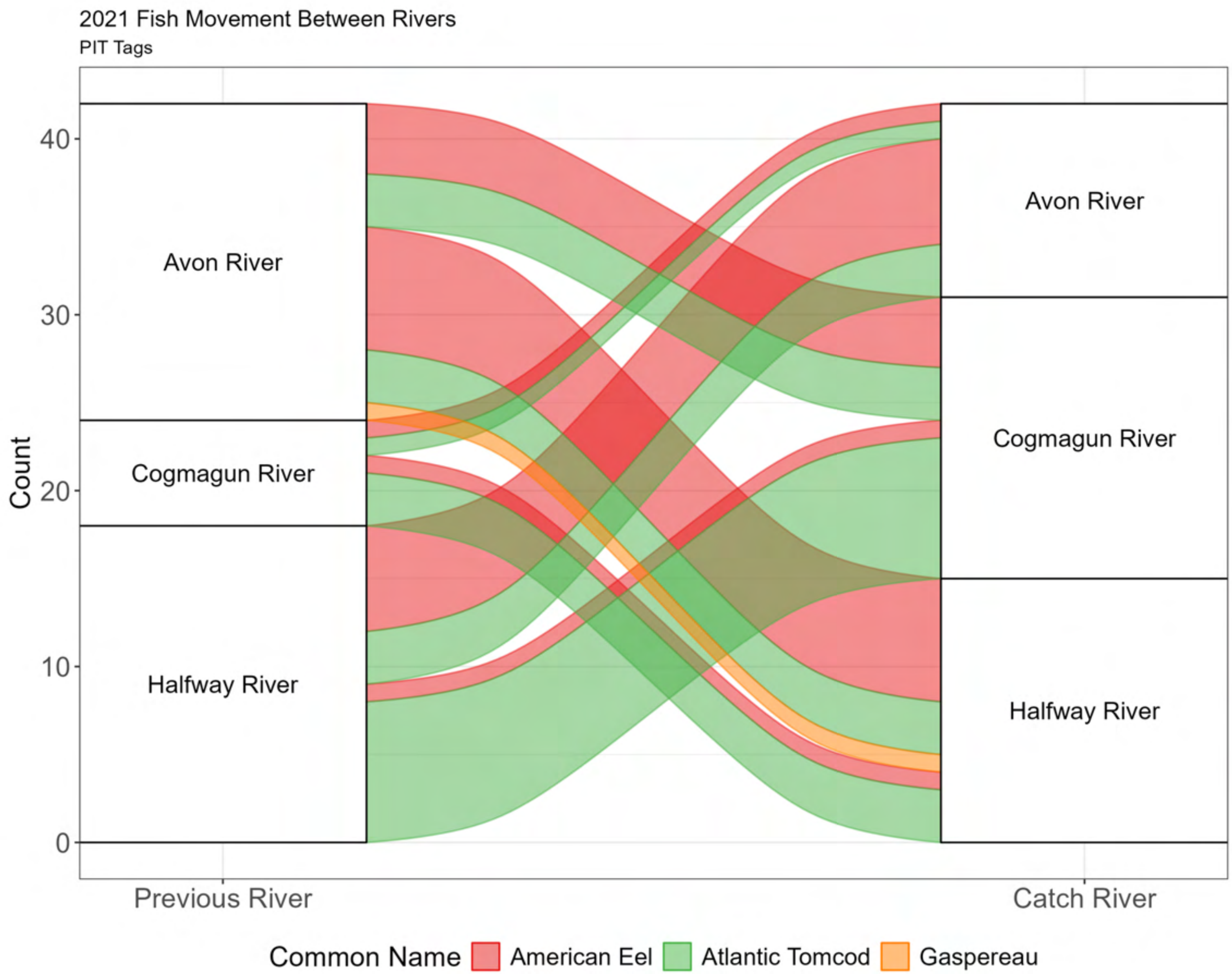


Figure 24 PIT tags deployed in all previous years (previous river) and recaptured at other sites in 2021.

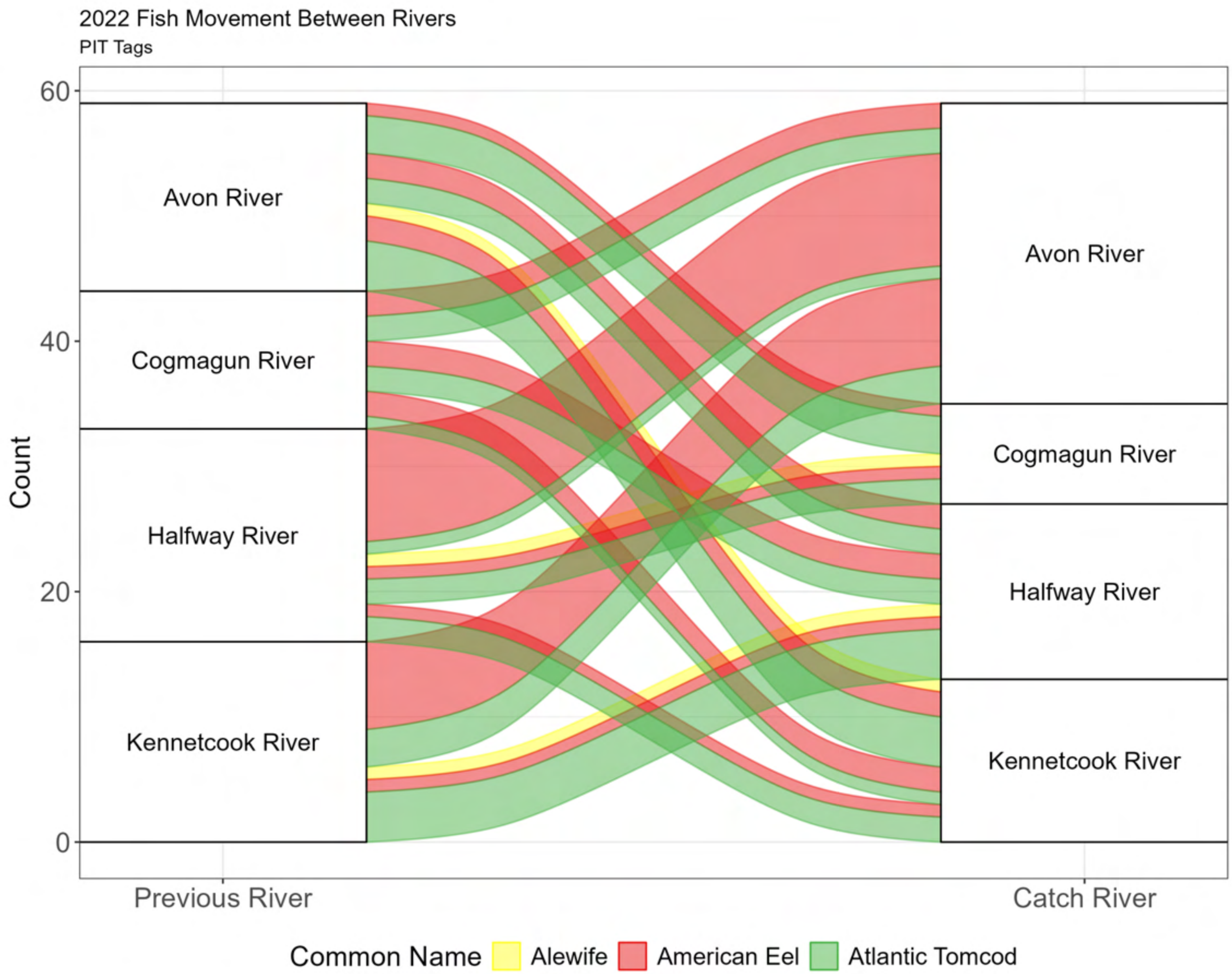


Figure 25 PIT tags deployed in all previous years (previous river) and recaptured at other sites in 2022.

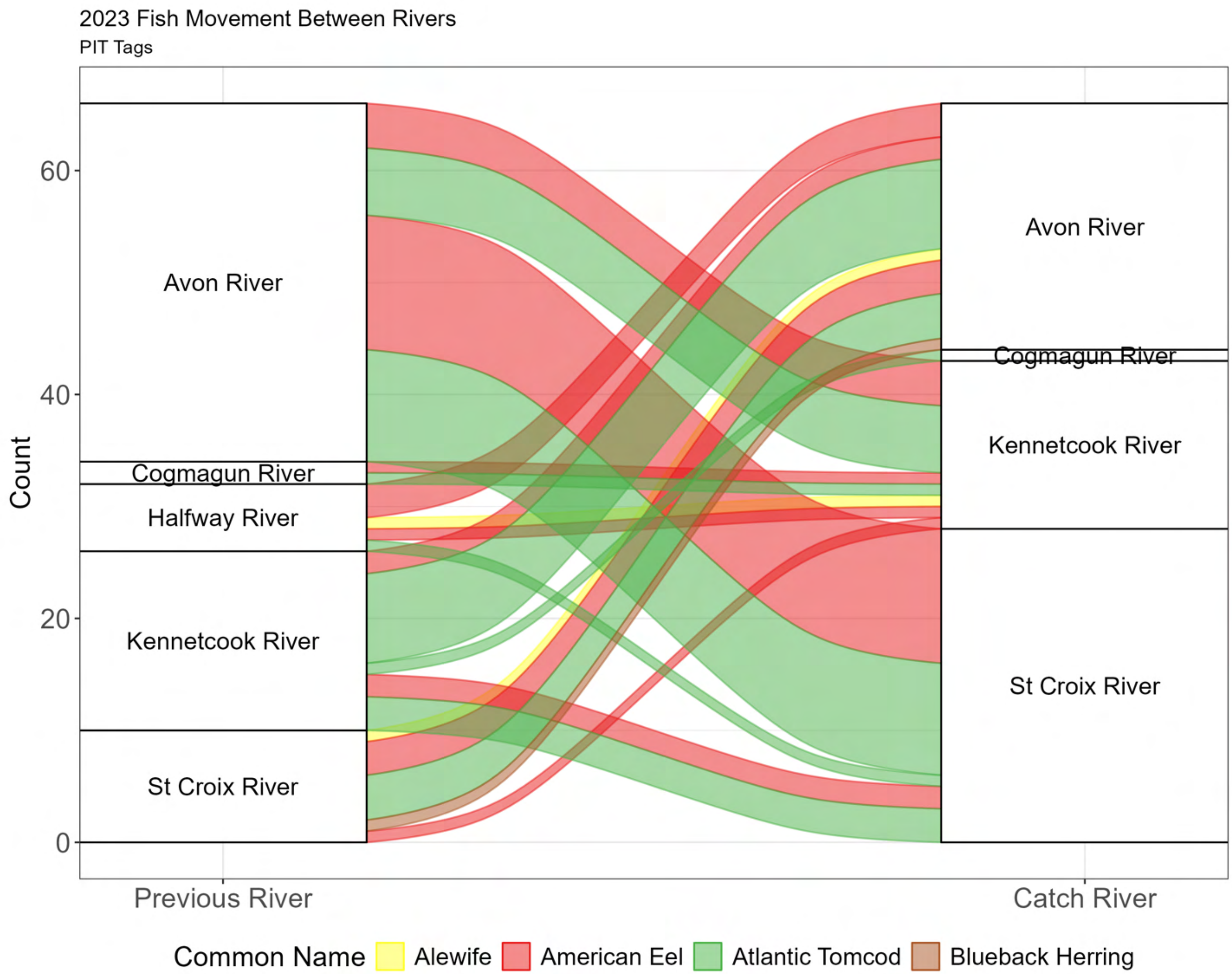


Figure 26 PIT tags deployed in all previous years (previous river) and recaptured at other sites in 2023.

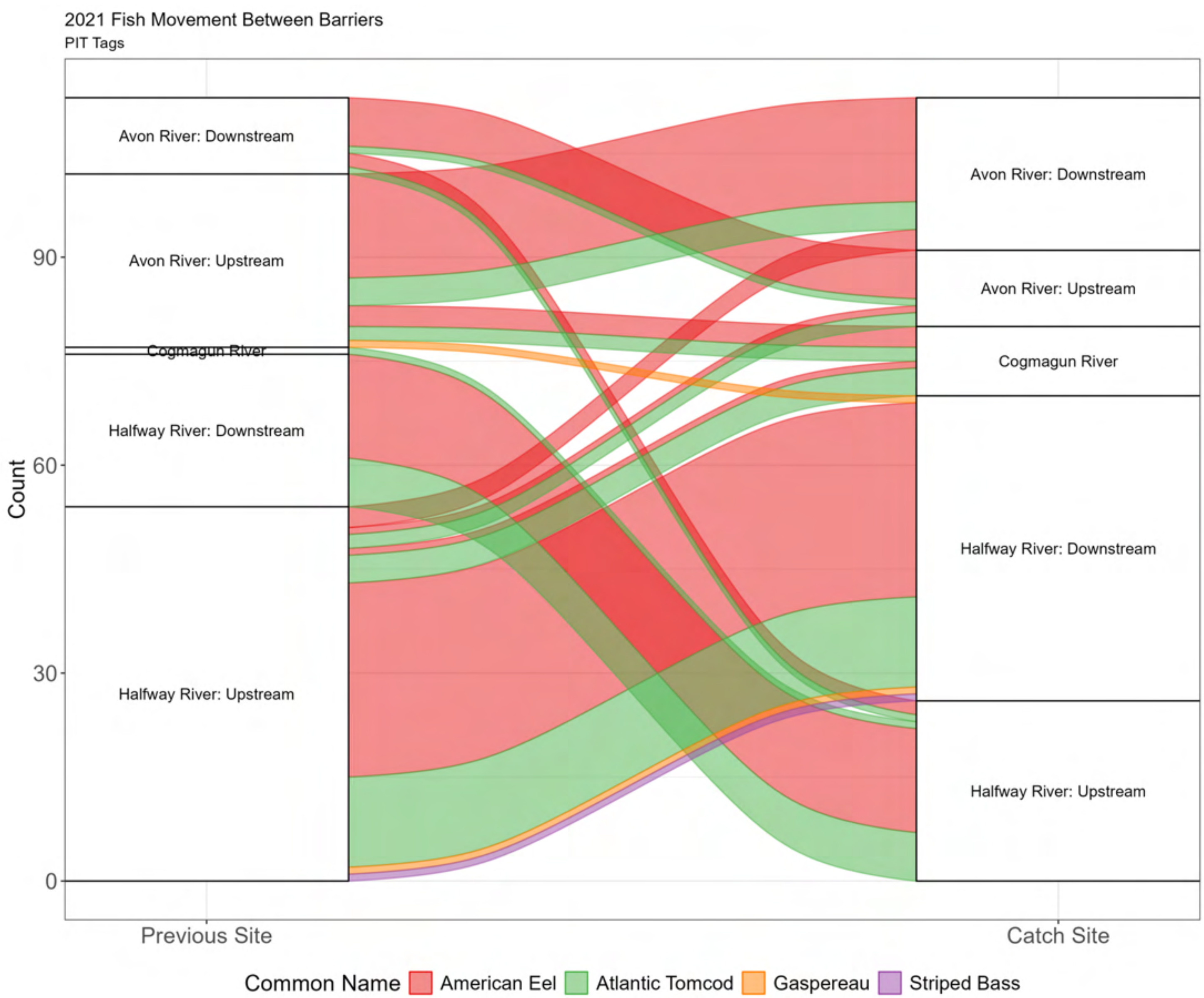


Figure 27 PIT tags deployed in all previous years (previous river) and detected to pass through a barrier or to another site in 2021.

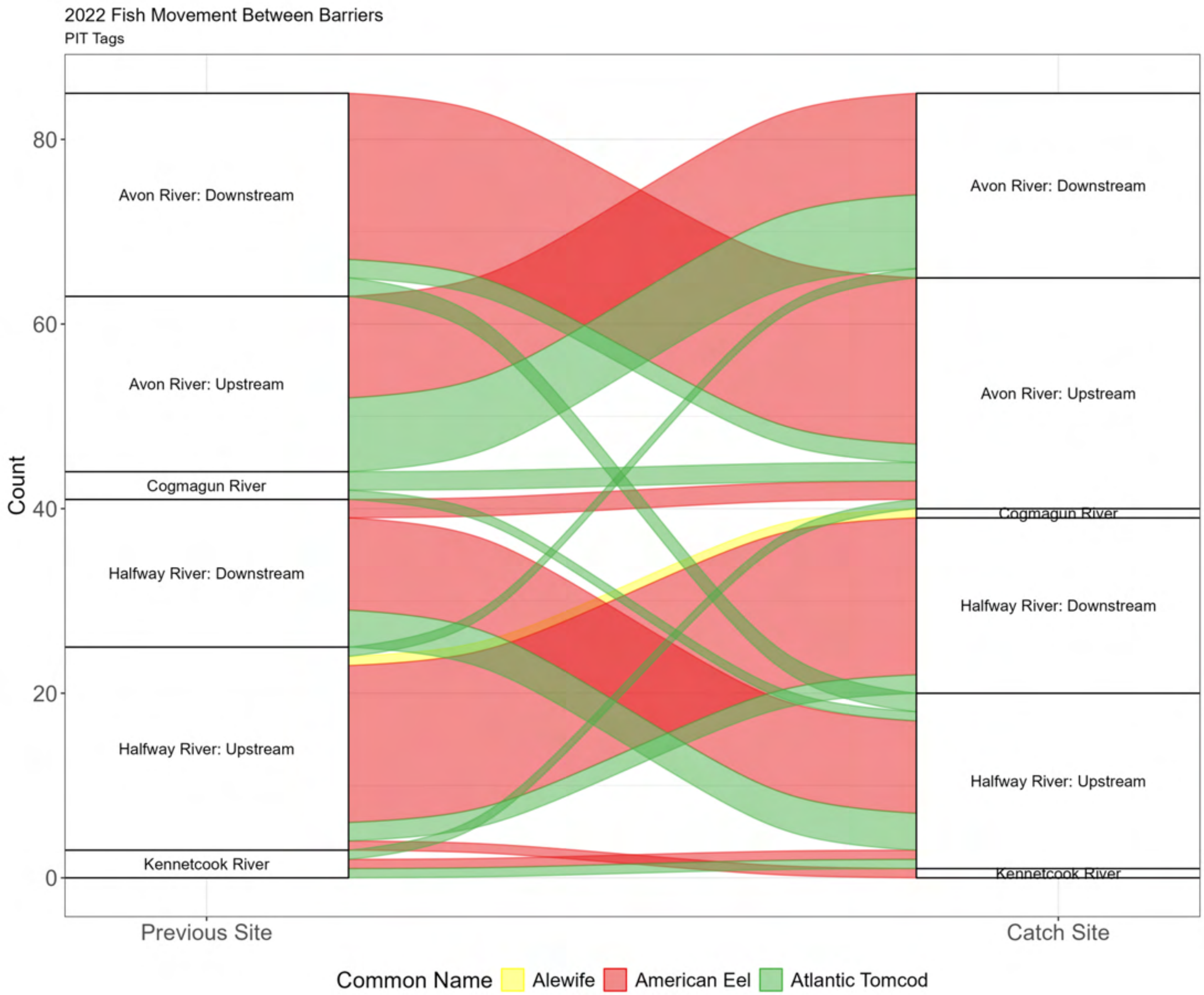


Figure 28 PIT tags deployed in all previous years (previous river) and detected to pass through a barrier or to another site in 2022.

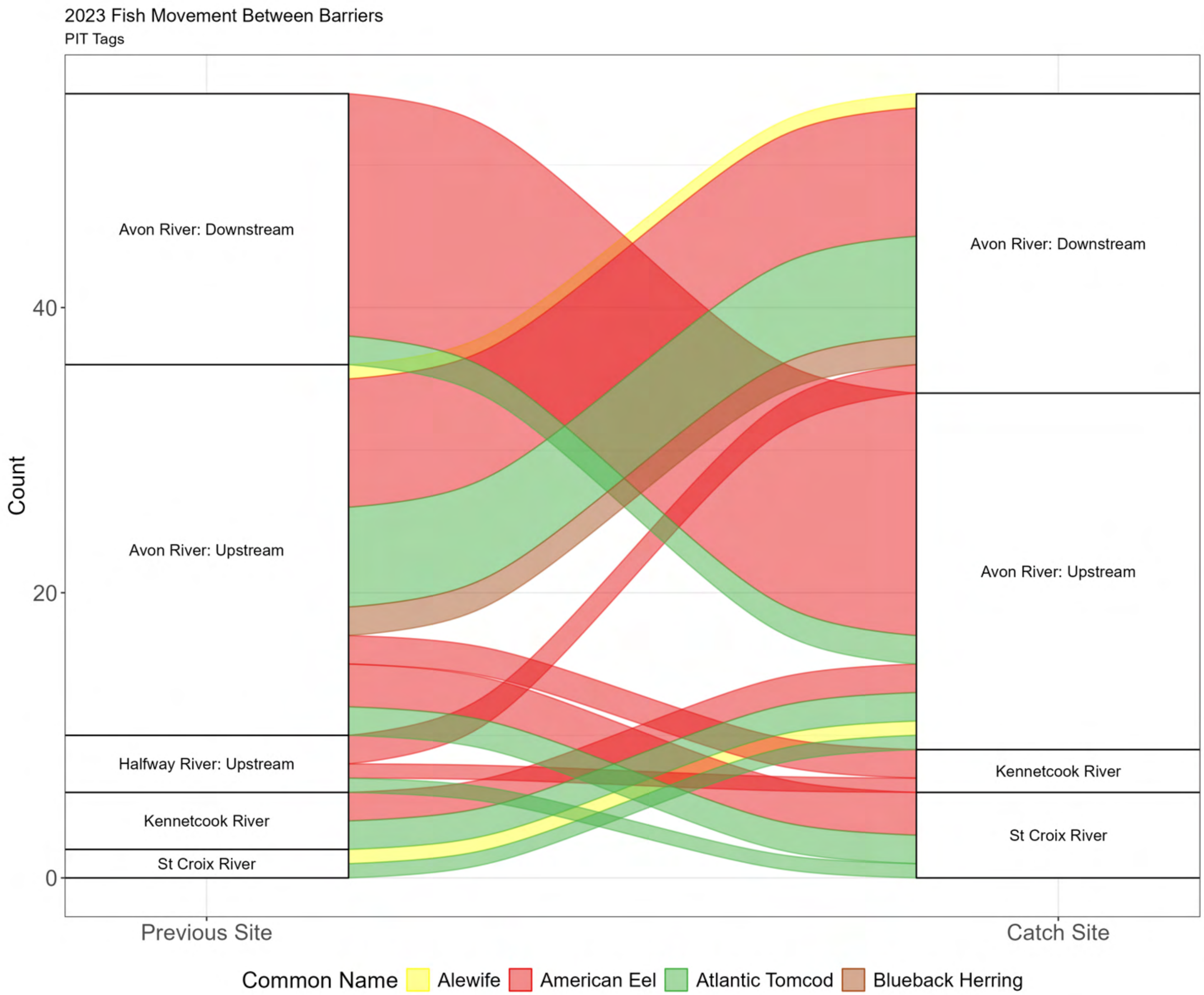


Figure 29 PIT tags deployed in all previous years (previous river) and detected to pass through a barrier or to another site in 2023.

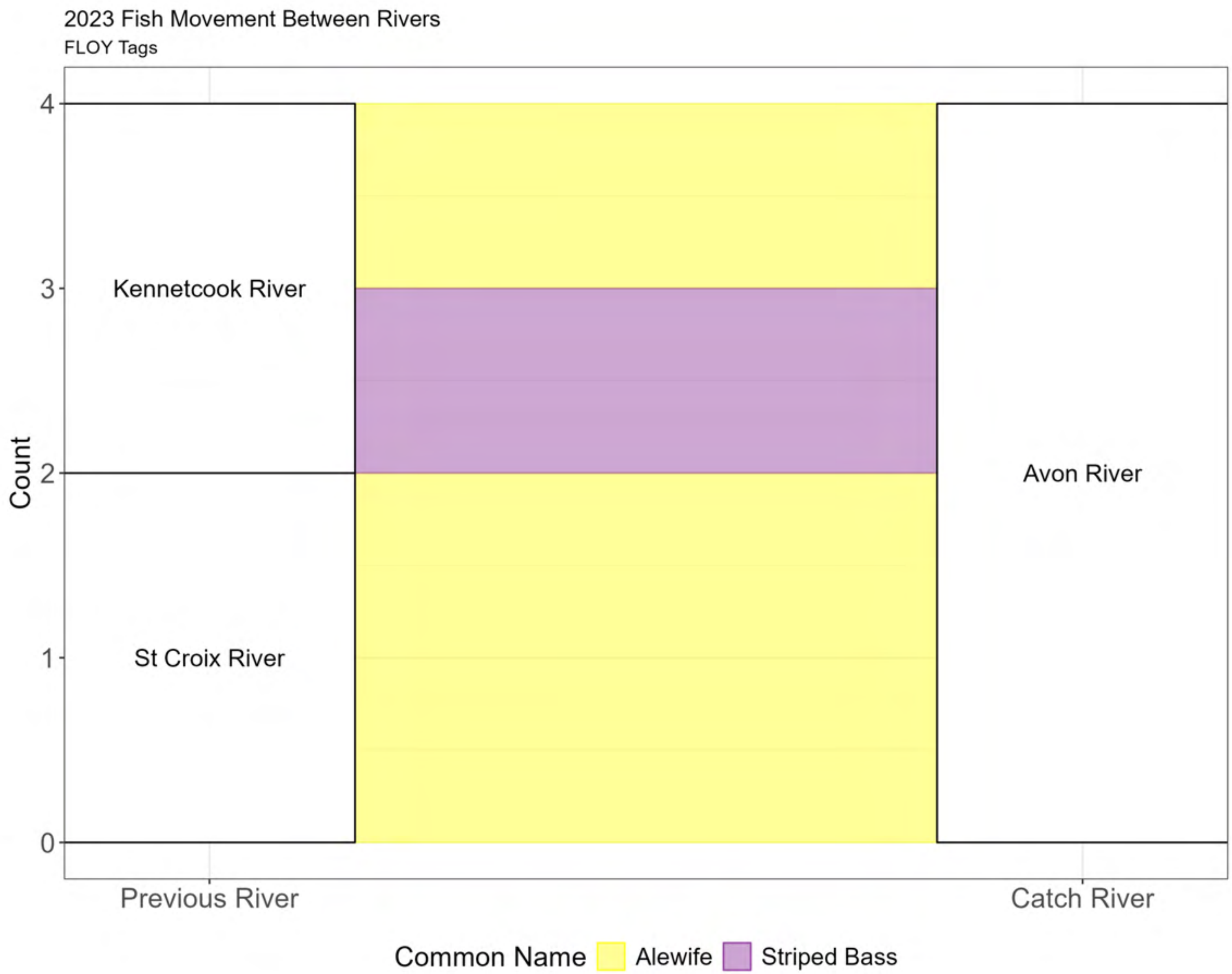


Figure 30 T-bar tags deployed in all previous years (previous river) and recaptured at other sites in 2023.

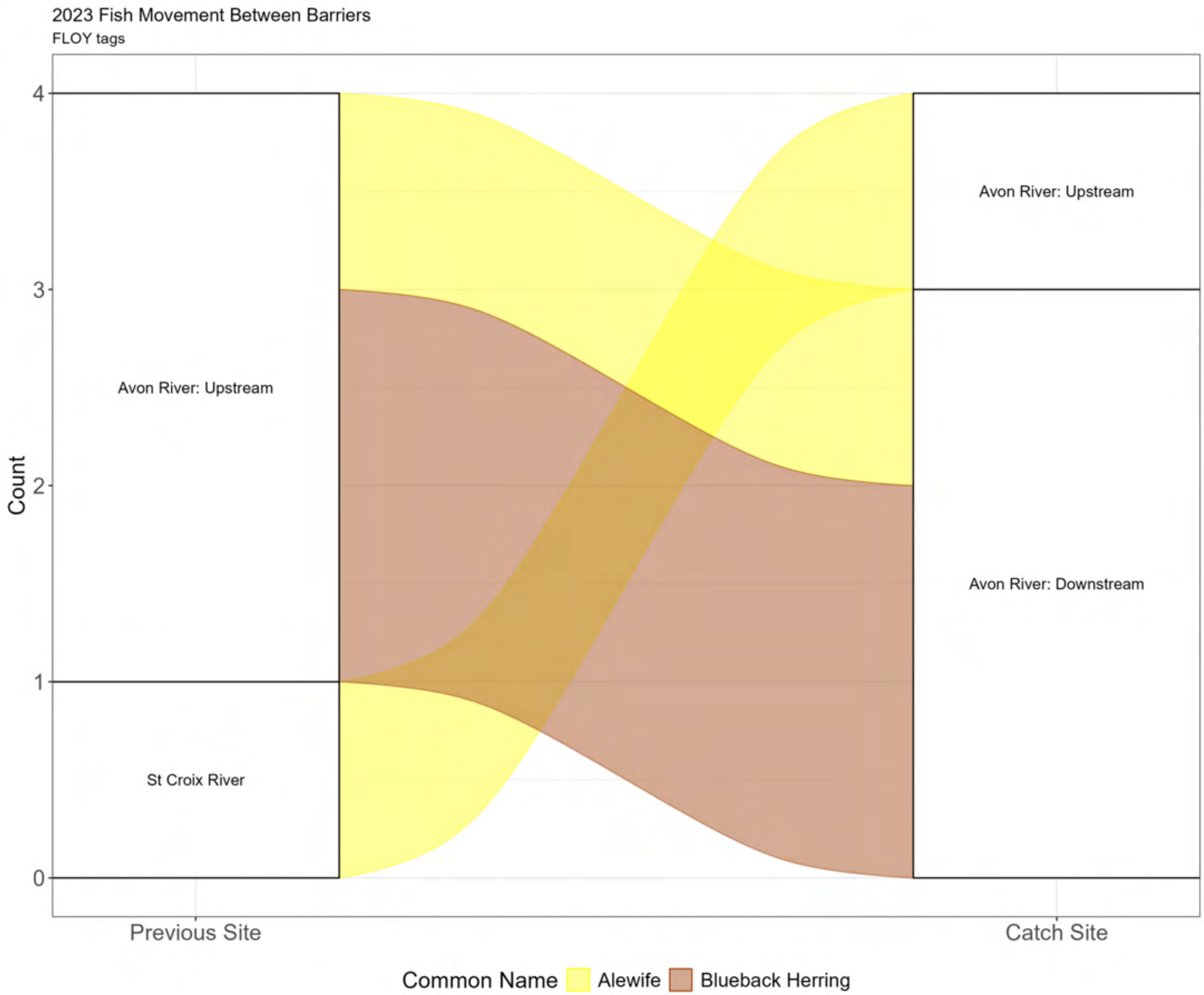
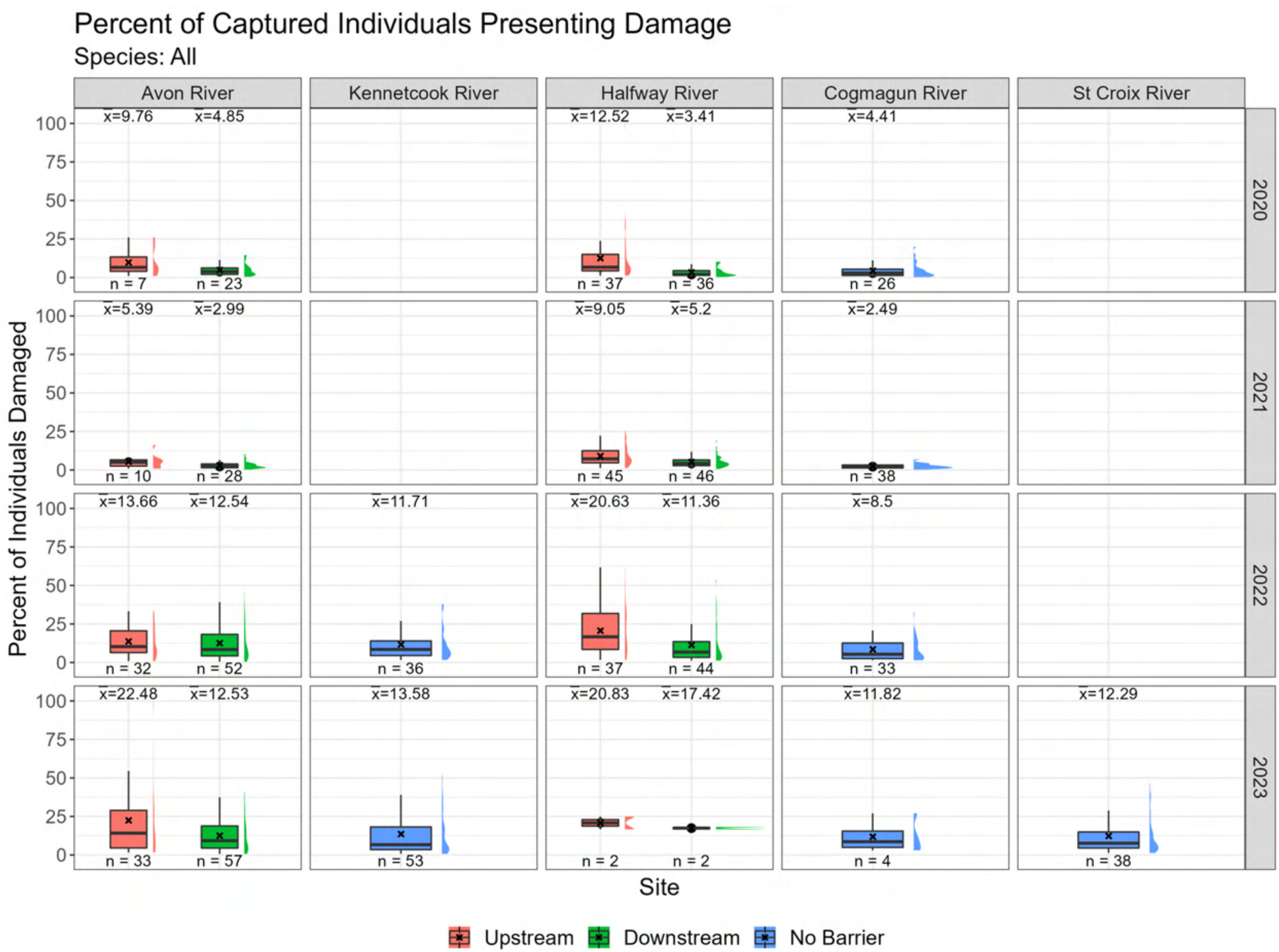


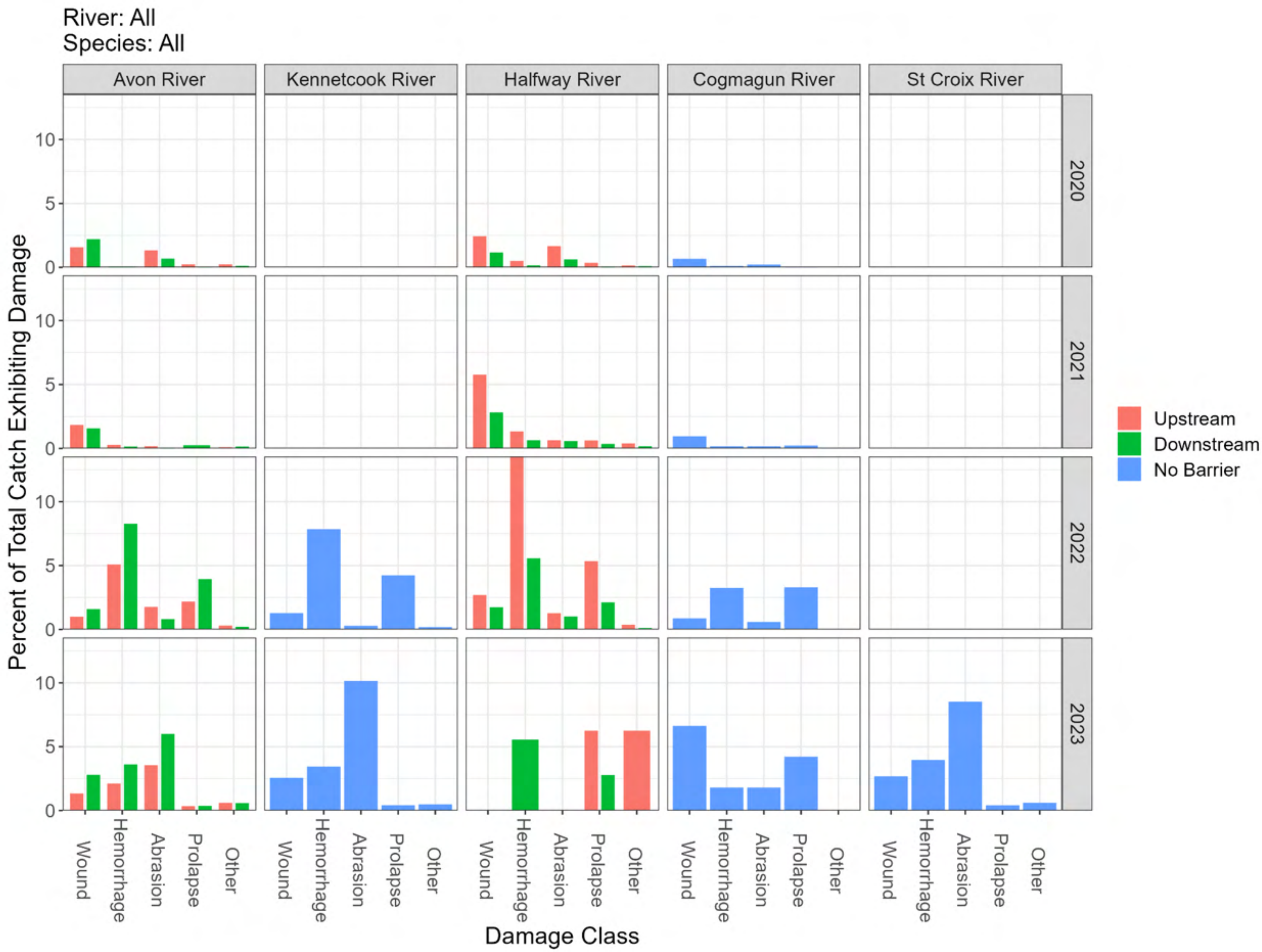
Figure 31 T-bar tags deployed in all previous years (previous river) and detected to pass through a barrier or to another site in 2023.

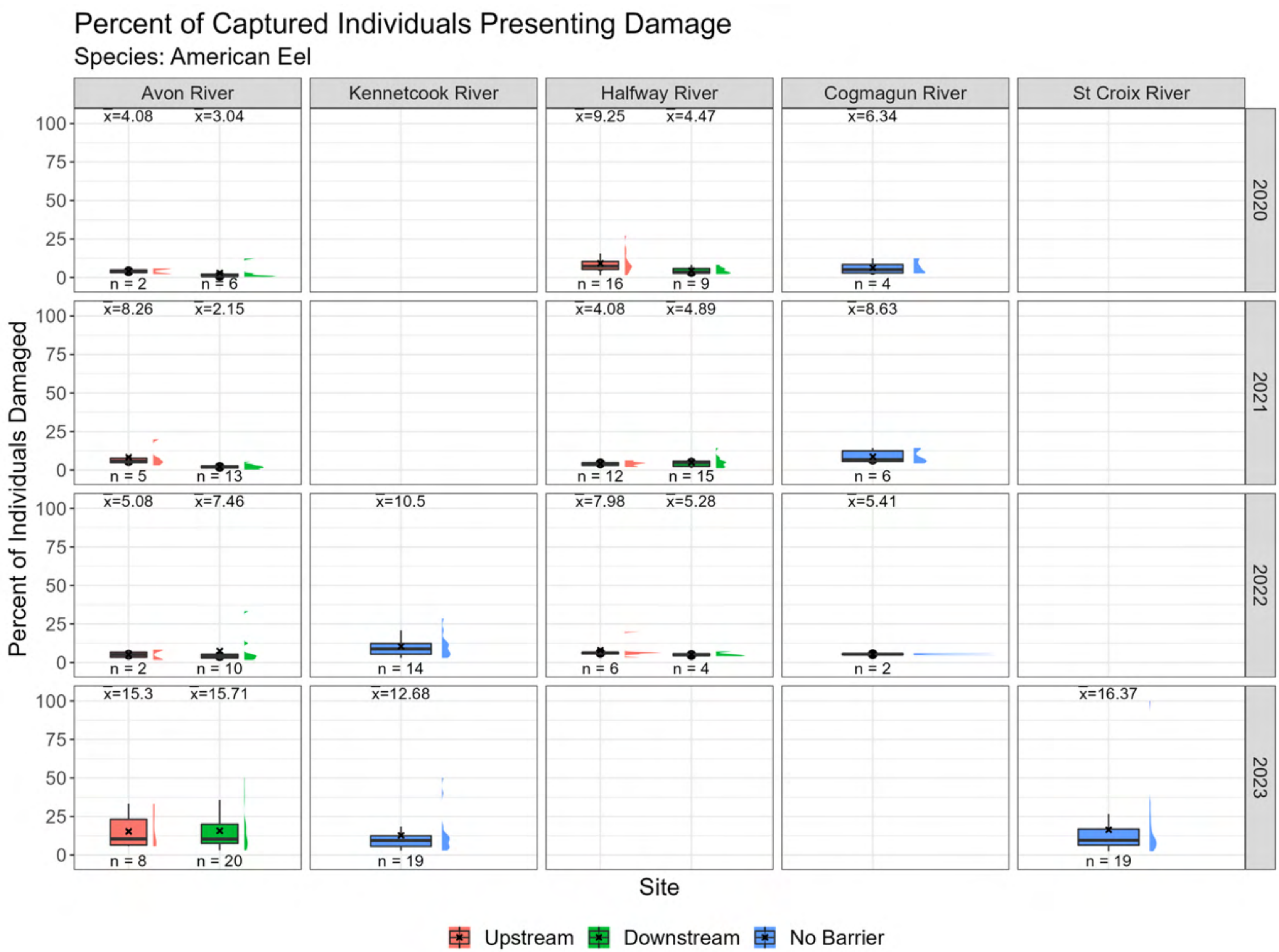
Appendix D - Fish Damage

x is the mean percent damage observed for a given species and year.

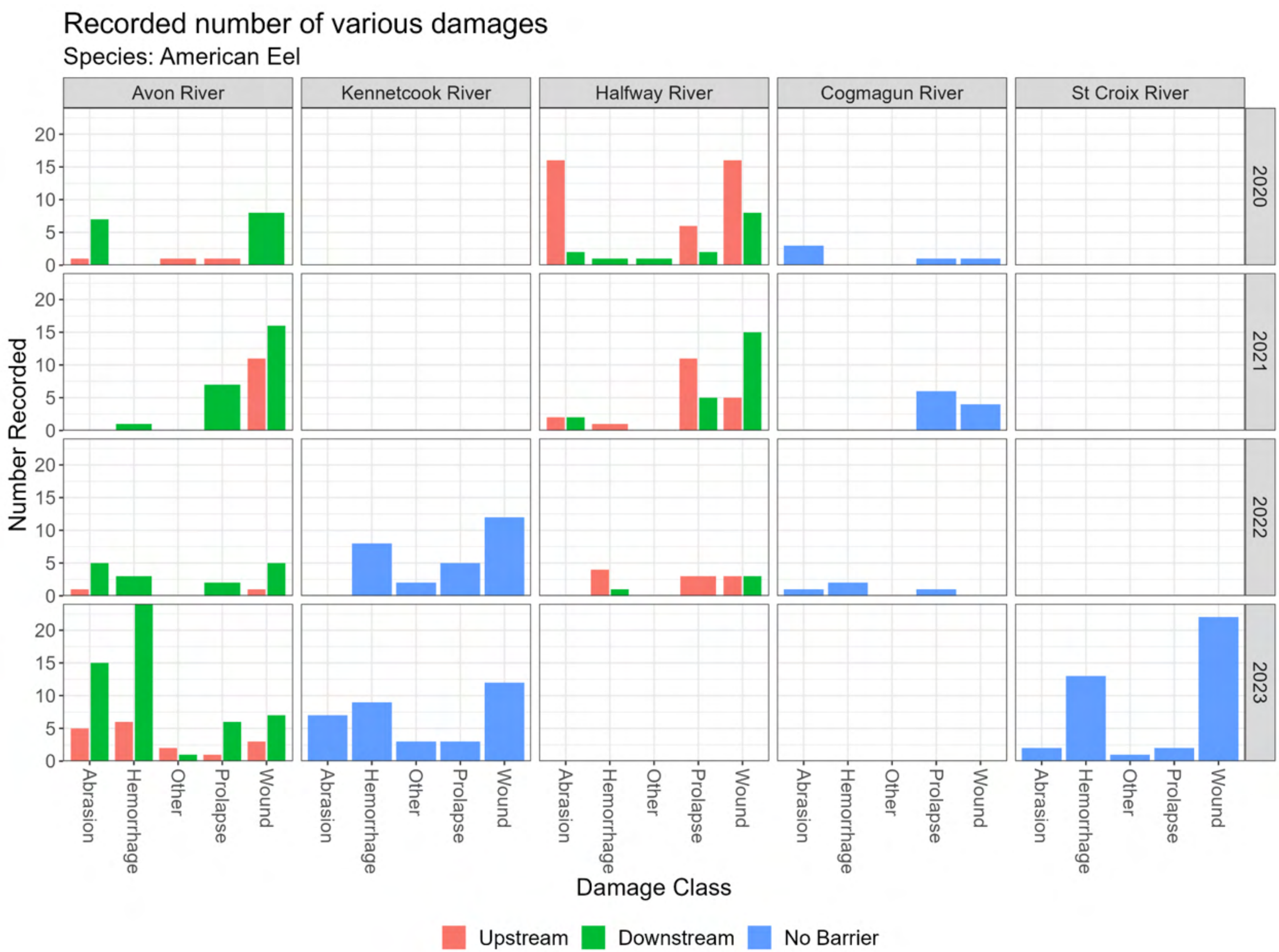
n is the number of fishing events that occurred during which damage was also observed for the given species in the specified year.


Percent of Captured Individuals Presenting Damage
Species: All
Avon River
Kennetcook River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
Percent of Individuals Damaged
Site
x̄=9.76
x̄=4.85
x̄=12.52
x̄=3.41
x̄=4.41
n = 7
n = 23
n = 37
n = 36
n = 26
x̄=5.39
x̄=2.99
x̄=9.05
x̄=5.2
x̄=2.49
n = 10
n = 28
n = 45
n = 46
n = 38
x̄=13.66
x̄=12.54
x̄=11.71
x̄=20.63
x̄=11.36
x̄=8.5
n = 32
n = 52
n = 36
n = 37
n = 44
n = 33
x̄=22.48
x̄=12.53
x̄=13.58
x̄=20.83
x̄=17.42
x̄=11.82
x̄=12.29
n = 33
n = 57
n = 53
n = 2
n = 2
n = 4
n = 38
Upstream
Downstream
No Barrier

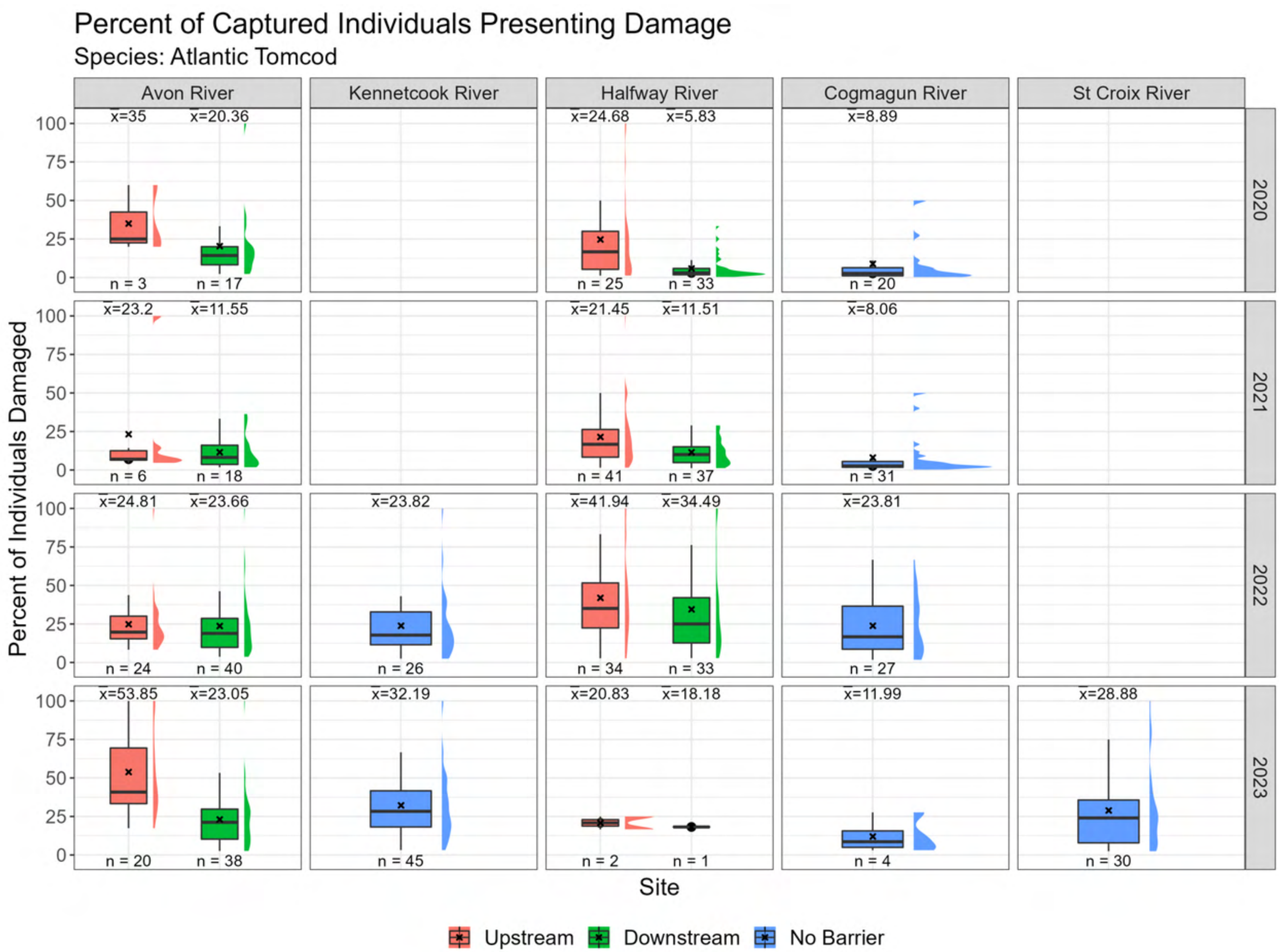

River: All
Species: All
Avon River
Kennetcook River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
Percent of Total Catch Exhibiting Damage
0
5
10
Wound
Hemorrhage
Abrasion
Prolapse
Other
Damage Class
Upstream
Downstream
No Barrier

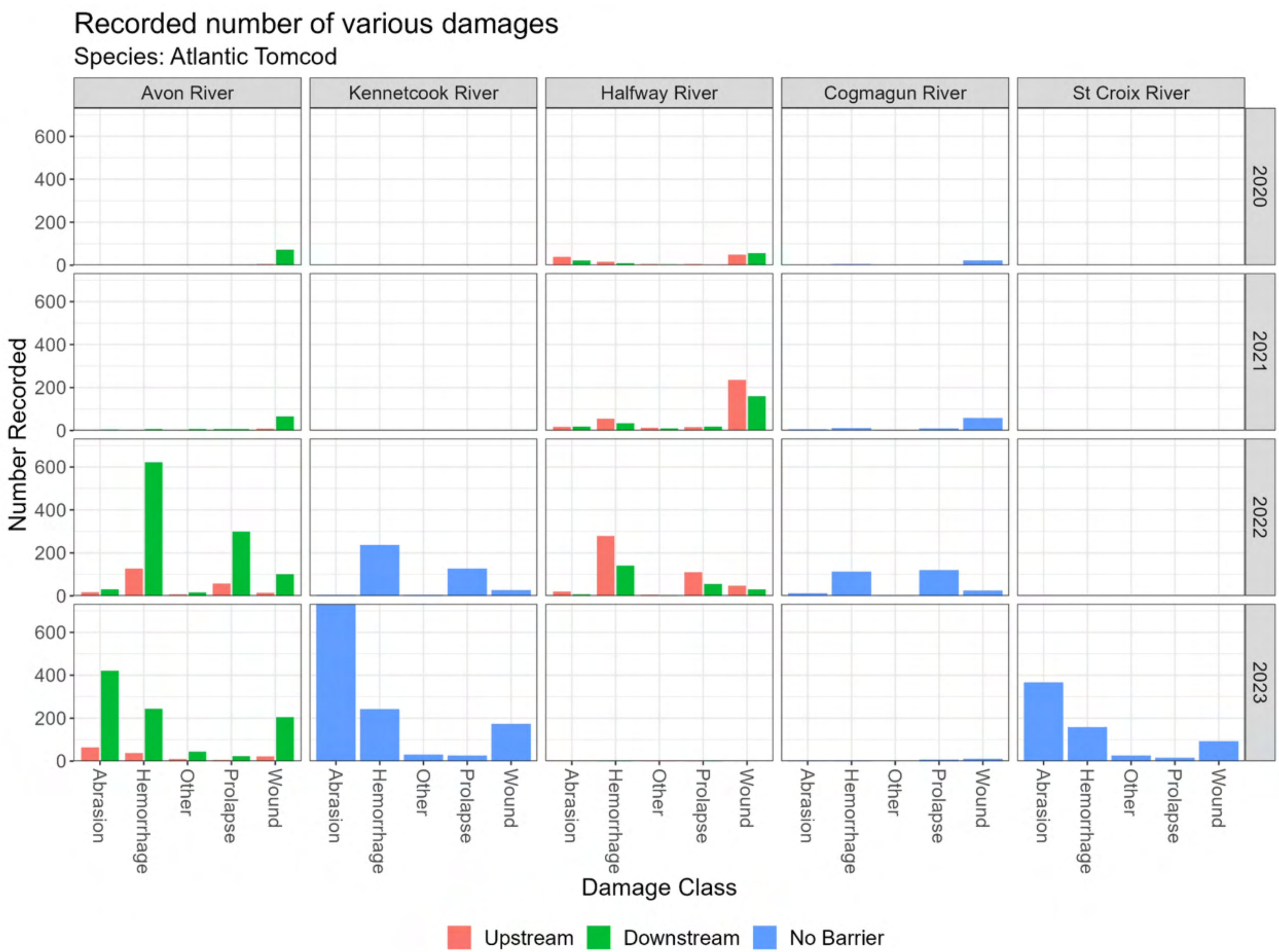


Percent of Captured Individuals Presenting Damage
Species: American Eel
Avon River
Kennetcook River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
x̄=4.08
x̄=3.04
x̄=9.25
x̄=4.47
x̄=6.34
n = 2
n = 6
n = 16
n = 9
n = 4
x̄=8.26
x̄=2.15
x̄=4.08
x̄=4.89
x̄=8.63
n = 5
n = 13
n = 12
n = 15
n = 6
x̄=5.08
x̄=7.46
x̄=10.5
x̄=7.98
x̄=5.28
x̄=5.41
n = 2
n = 10
n = 14
n = 6
n = 4
n = 2
x̄=15.3
x̄=15.71
x̄=12.68
x̄=16.37
n = 8
n = 20
n = 19
n = 19
Percent of Individuals Damaged
Site
Upstream
Downstream
No Barrier

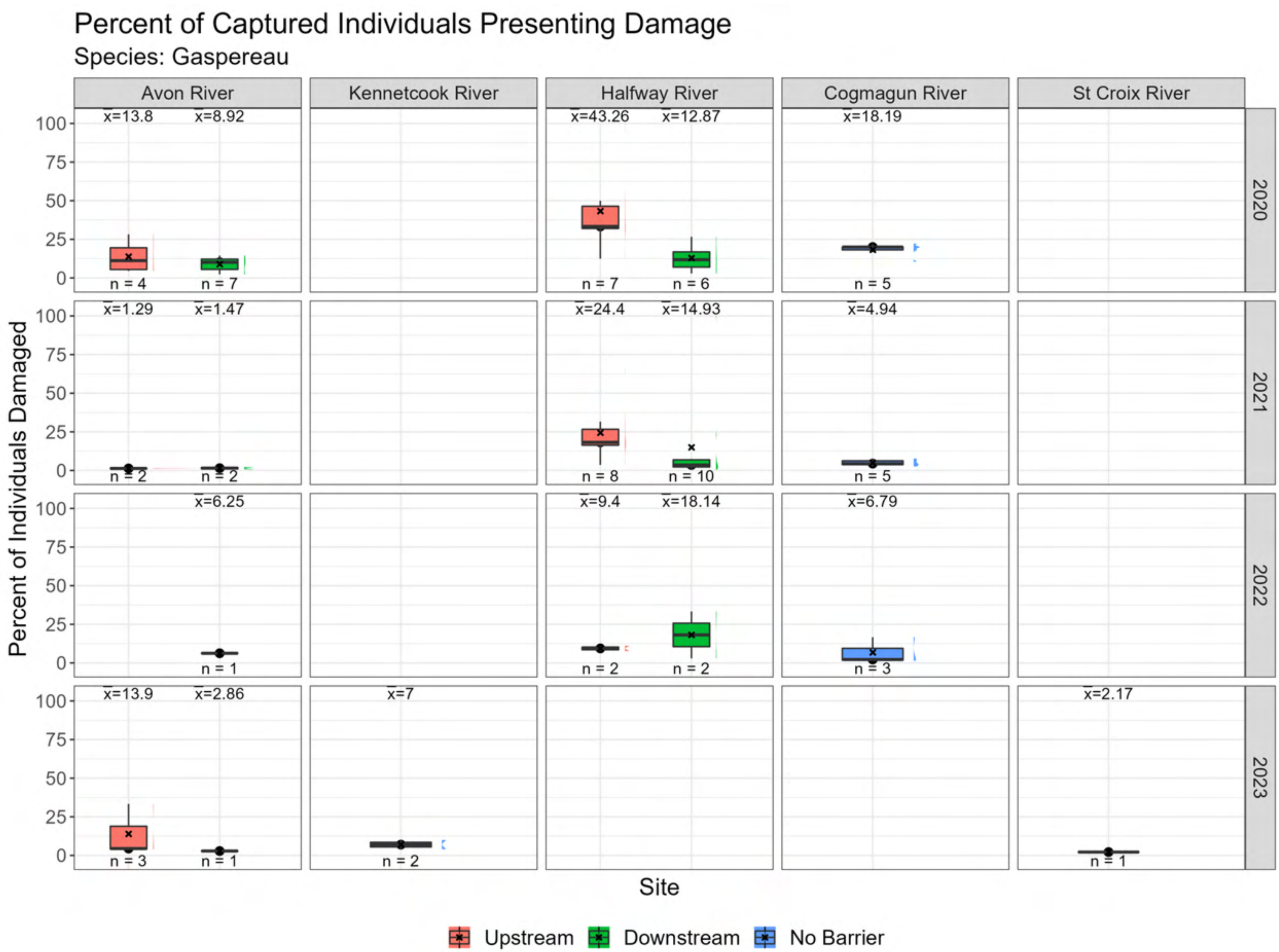


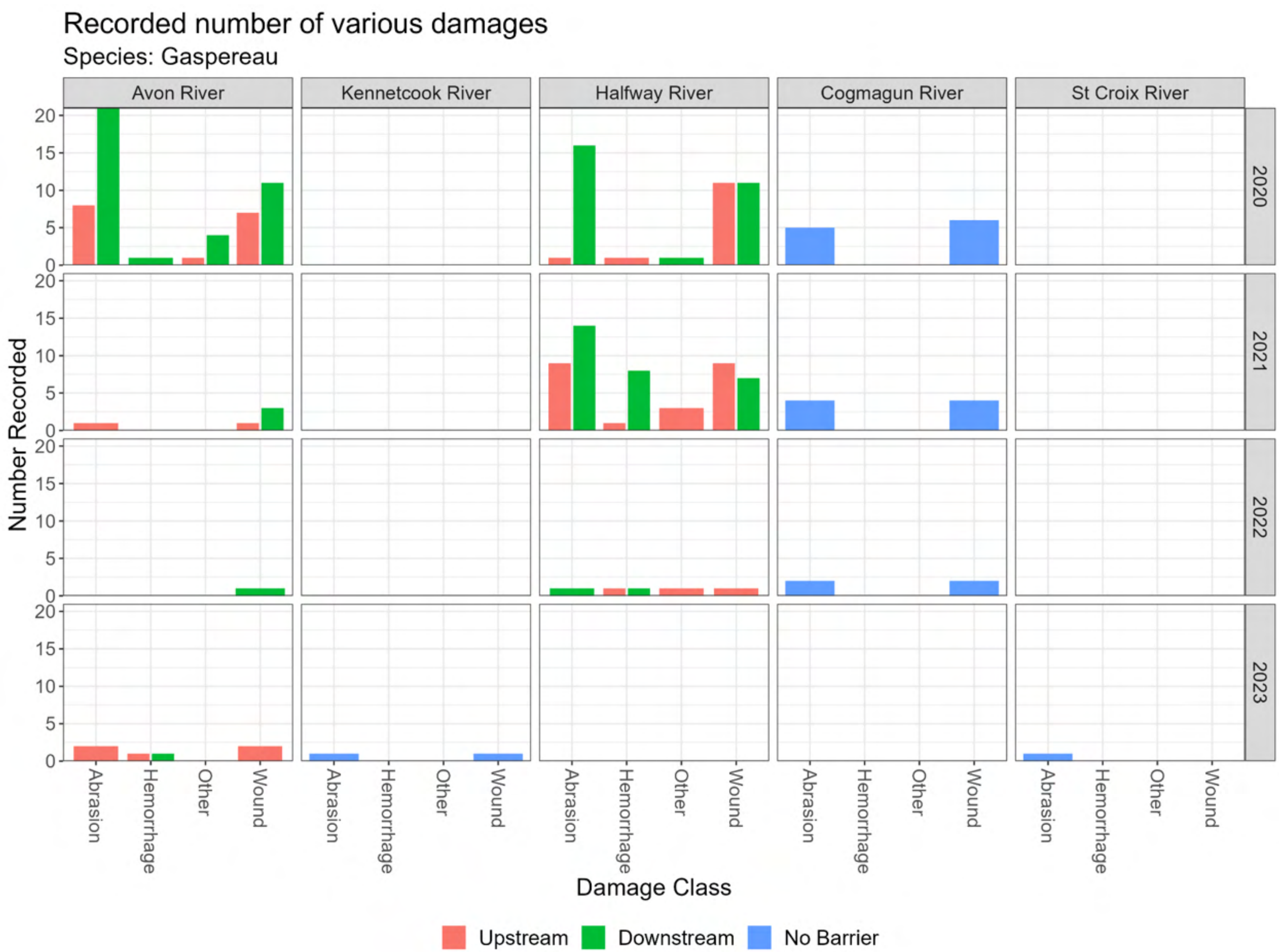
Recorded number of various damages
Species: American Eel
Avon River
Kennetcook River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
Number Recorded
0
5
10
15
20
Abrasion
Hemorrhage
Other
Prolapse
Wound
Damage Class
Upstream
Downstream
No Barrier


Percent of Captured Individuals Presenting Damage
Species: Atlantic Tomcod
Avon River
Kennetcook River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
x=35
x=20.36
n = 3
n = 17
x=24.68
x=5.83
n = 25
n = 33
x=8.89
n = 20
x=23.2
x=11.55
n = 6
n = 18
x=21.45
x=11.51
n = 41
n = 37
x=8.06
n = 31
x=24.81
x=23.66
n = 24
n = 40
x=23.82
n = 26
x=41.94
x=34.49
n = 34
n = 33
x=23.81
n = 27
x=53.85
x=23.05
n = 20
n = 38
x=32.19
n = 45
x=20.83
x=18.18
n = 2
n = 1
x=11.99
n = 4
x=28.88
n = 30
Percent of Individuals Damaged
100
75
50
25
0
Site
Upstream
Downstream
No Barrier

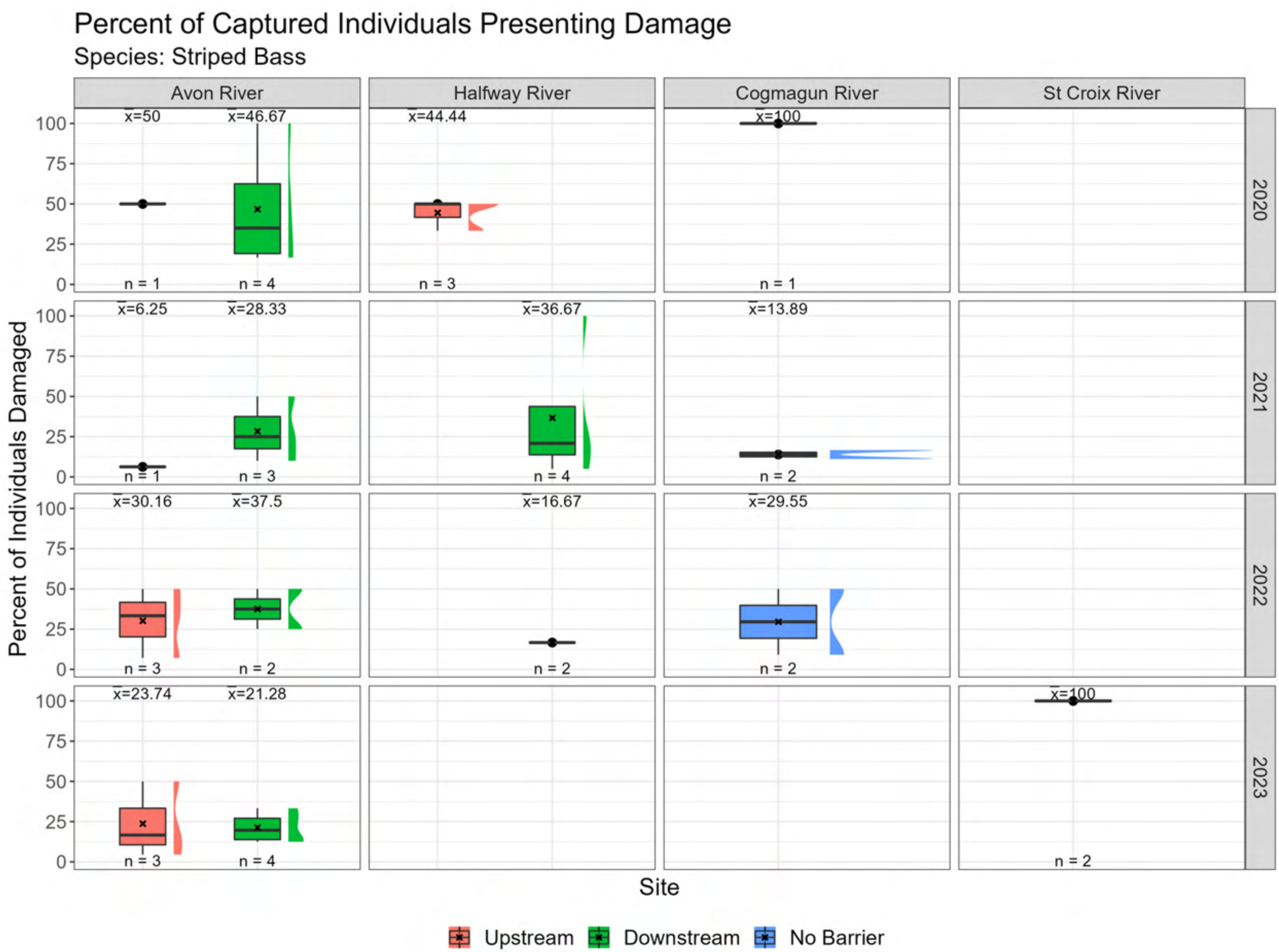


Recorded number of various damages
Species: Atlantic Tomcod
Avon River
Kennetcook River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
Number Recorded
0
200
400
600
Abrasion
Hemorrhage
Other
Prolapse
Wound
Damage Class
Upstream
Downstream
No Barrier

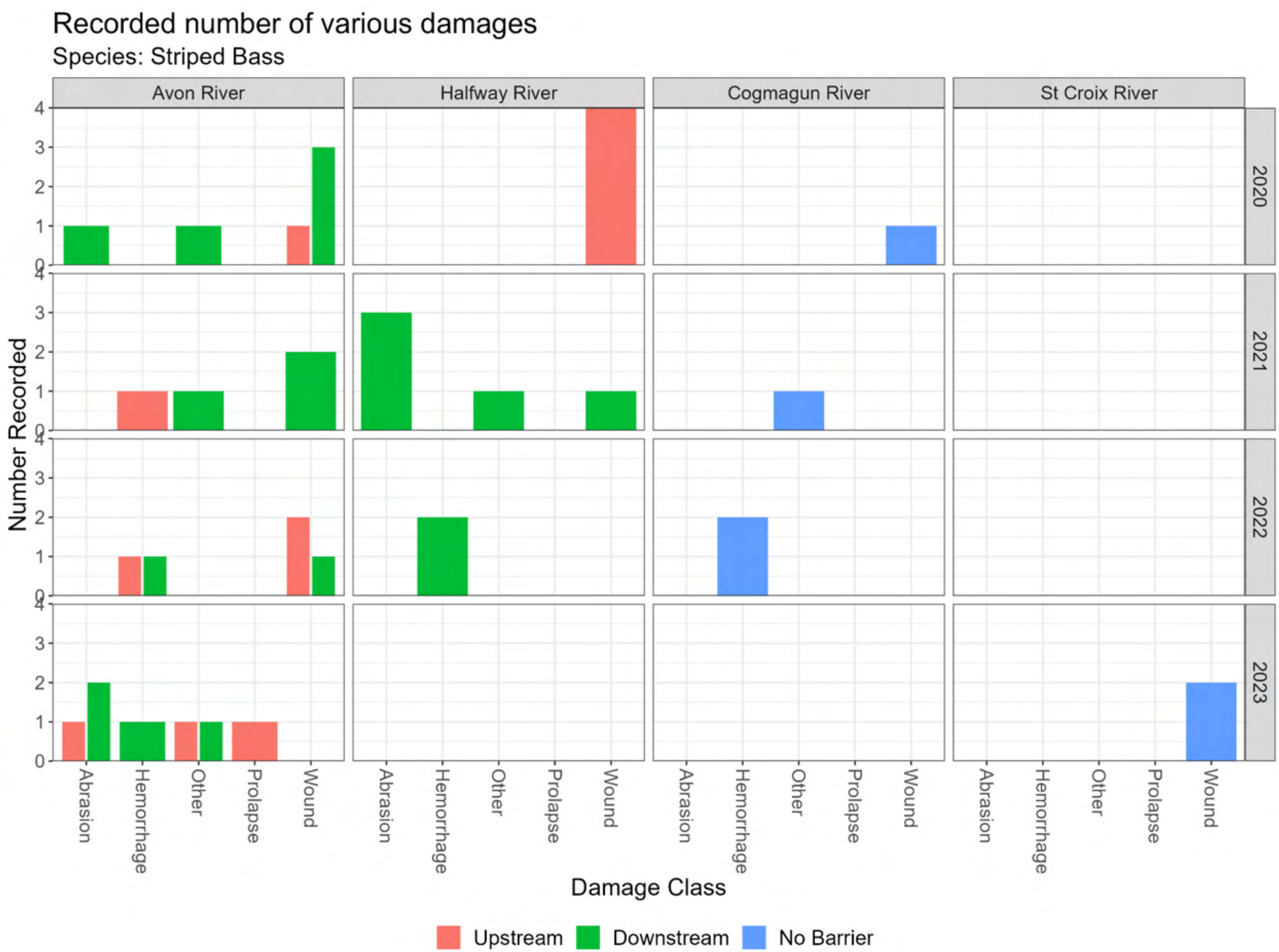

Percent of Captured Individuals Presenting Damage
Species: Gaspereau
Avon River
Kennetcook River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
Percent of Individuals Damaged
Site
x̄=13.8
x̄=8.92
n = 4
n = 7
x̄=43.26
x̄=12.87
n = 7
n = 6
x̄=18.19
n = 5
x̄=1.29
x̄=1.47
n = 2
n = 2
x̄=24.4
x̄=14.93
n = 8
n = 10
x̄=4.94
n = 5
x̄=6.25
n = 1
x̄=9.4
x̄=18.14
n = 2
n = 2
x̄=6.79
n = 3
x̄=13.9
x̄=2.86
n = 3
n = 1
x̄=7
n = 2
x̄=2.17
n = 1
Upstream
Downstream
No Barrier



Recorded number of various damages
Species: Gaspereau
Avon River
Kennetcook River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
Number Recorded
0
5
10
15
20
Abrasion
Hemorrhage
Other
Wound
Damage Class
Upstream
Downstream
No Barrier



Percent of Captured Individuals Presenting Damage
Species: Striped Bass
Avon River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
Percent of Individuals Damaged
Site
x̄=50
x̄=46.67
x̄=44.44
x̄=100
n = 1
n = 4
n = 3
n = 1
x̄=6.25
x̄=28.33
x̄=36.67
x̄=13.89
n = 1
n = 3
n = 4
n = 2
x̄=30.16
x̄=37.5
x̄=16.67
x̄=29.55
n = 3
n = 2
n = 2
n = 2
x̄=23.74
x̄=21.28
x̄=100
n = 3
n = 4
n = 2
Upstream
Downstream
No Barrier

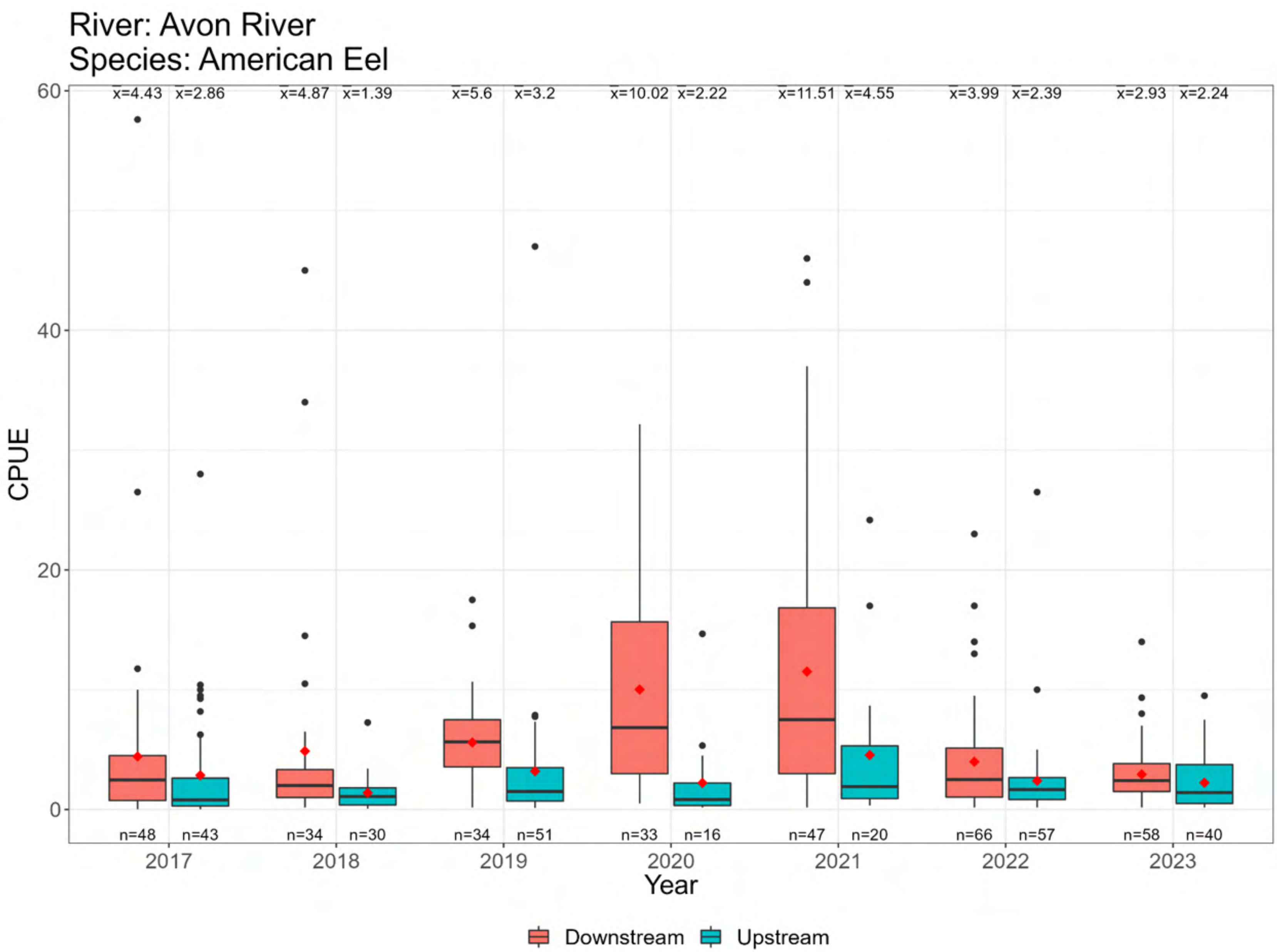


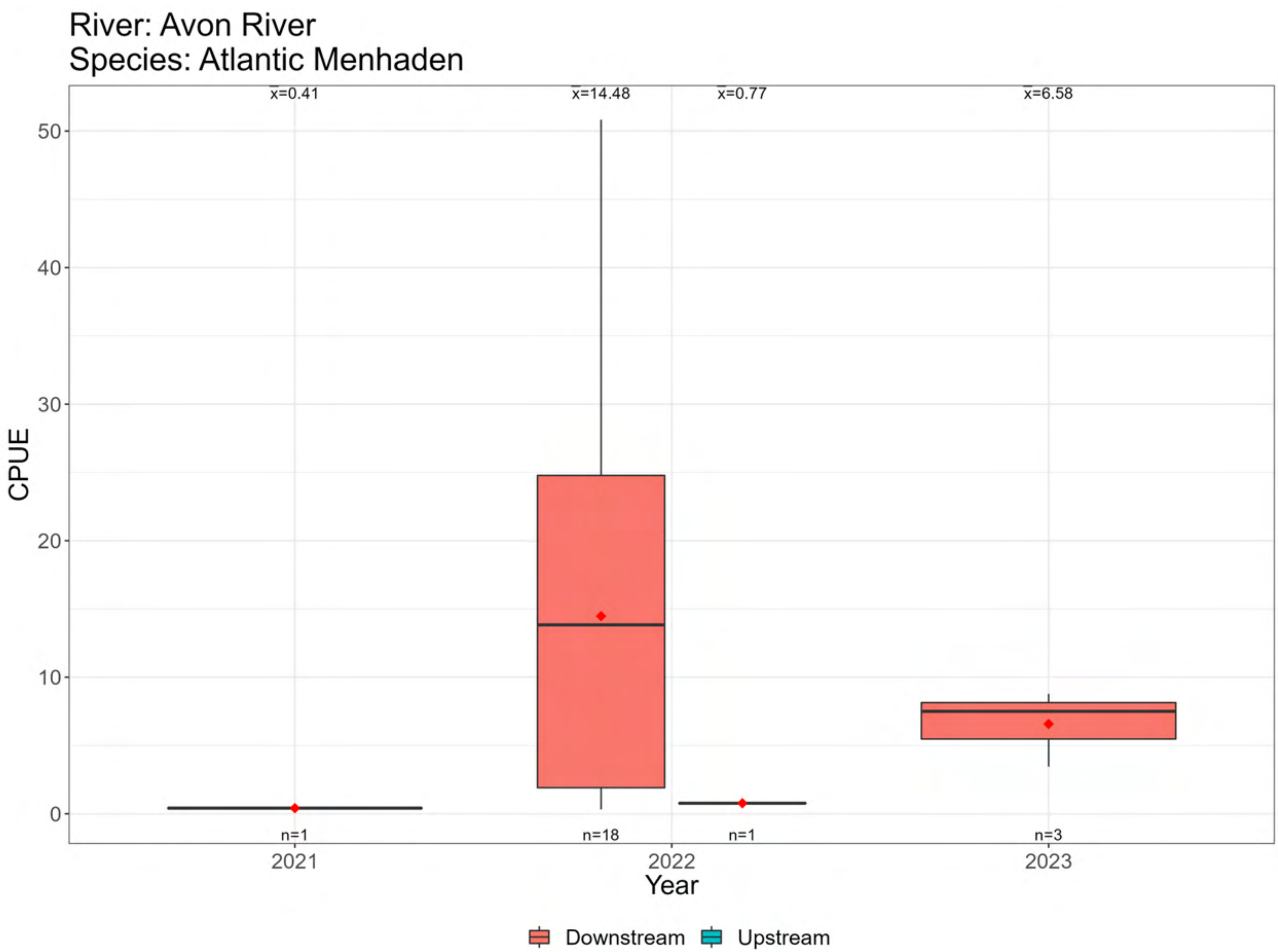
Recorded number of various damages
Species: Striped Bass
Avon River
Halfway River
Cogmagun River
St Croix River
2020
2021
2022
2023
Number Recorded
0
1
2
3
4
Abrasion
Hemorrhage
Other
Prolapse
Wound
Damage Class
Upstream
Downstream
No Barrier

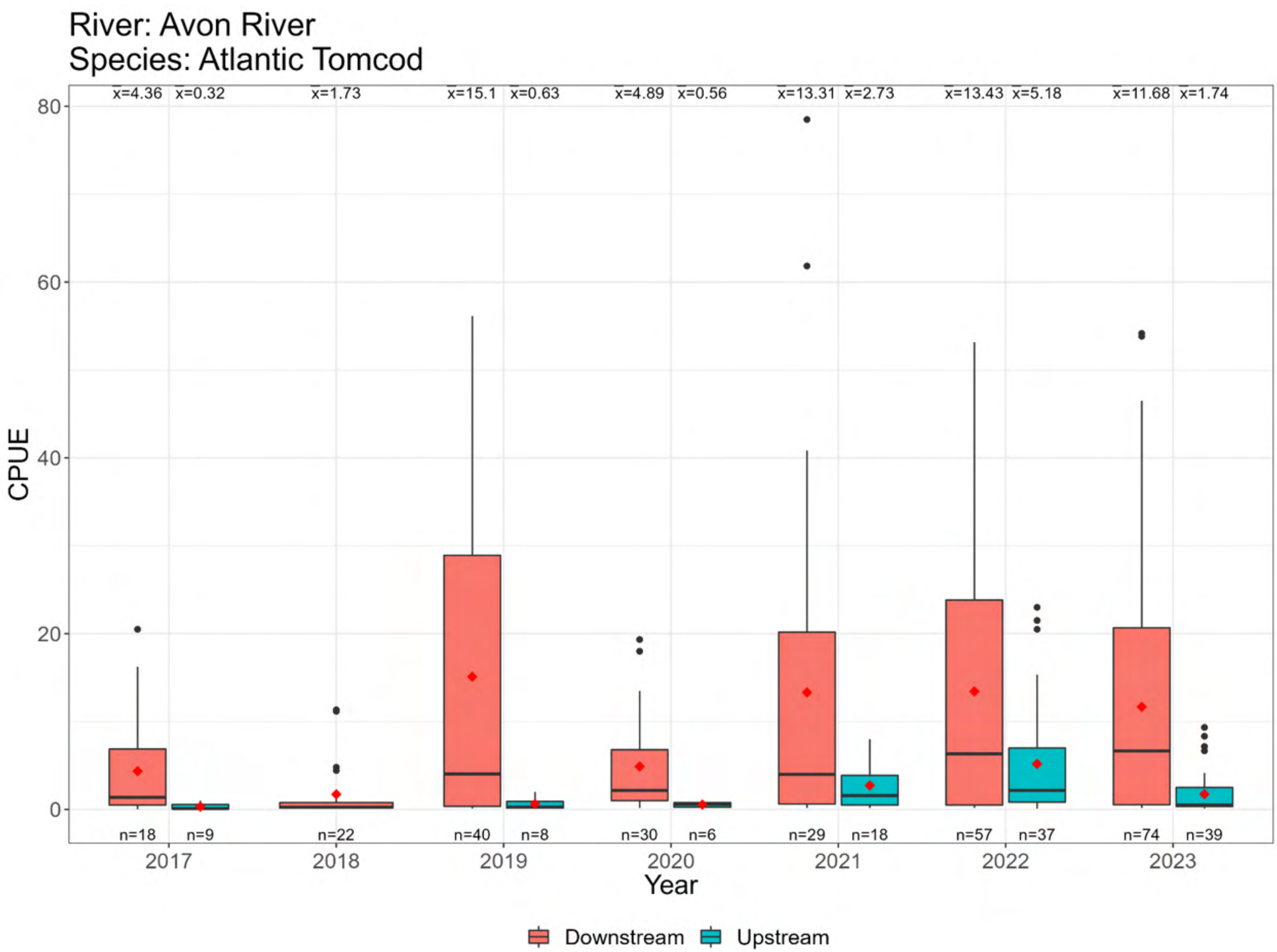
Appendix E - Comparison of mean CPUE Between Upstream and Downstream of Causeway

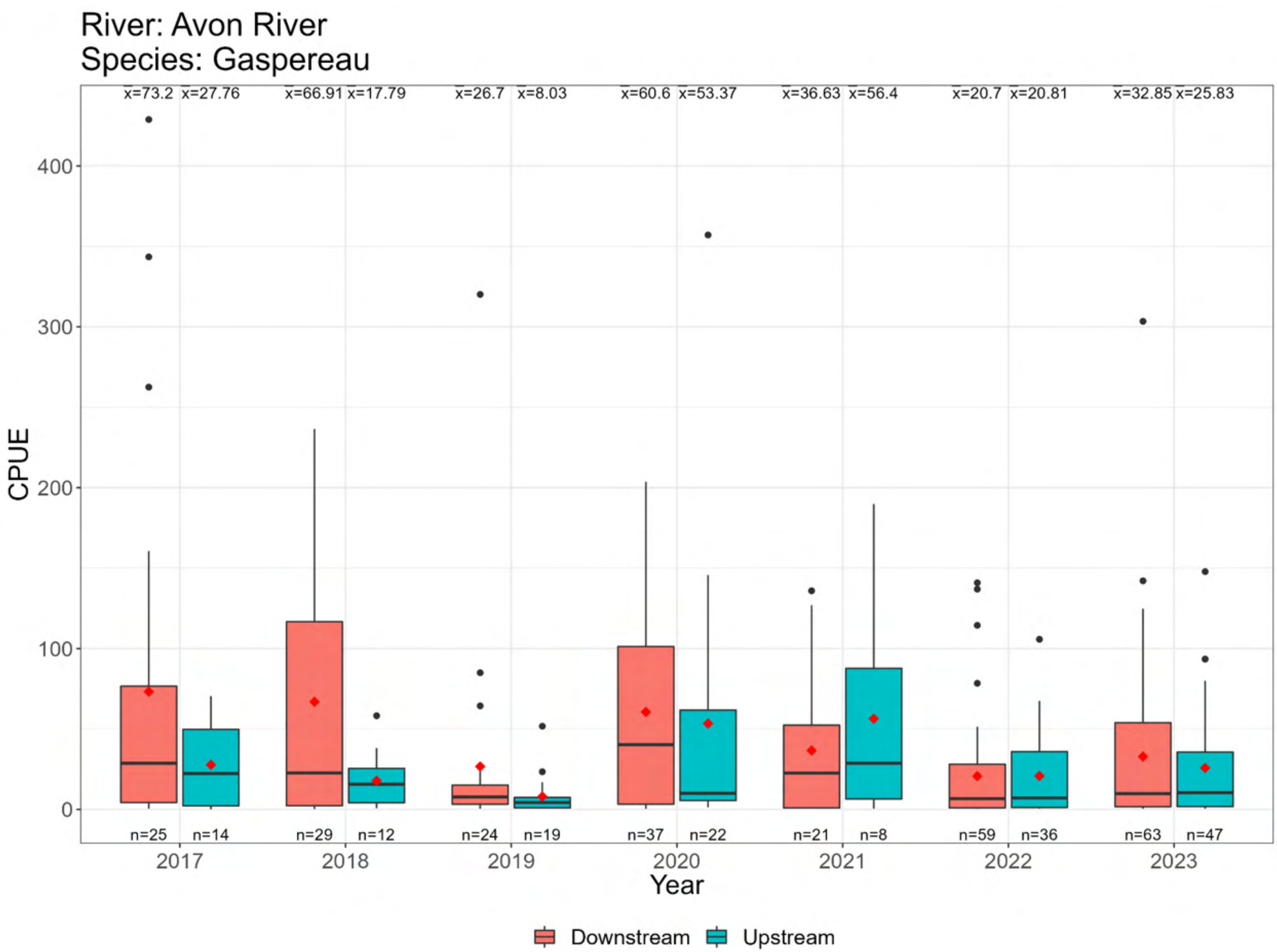
x is the mean CPUE observed for a given species and year.

n is the number of fishing events that occurred where the given species was caught, for the specified year.

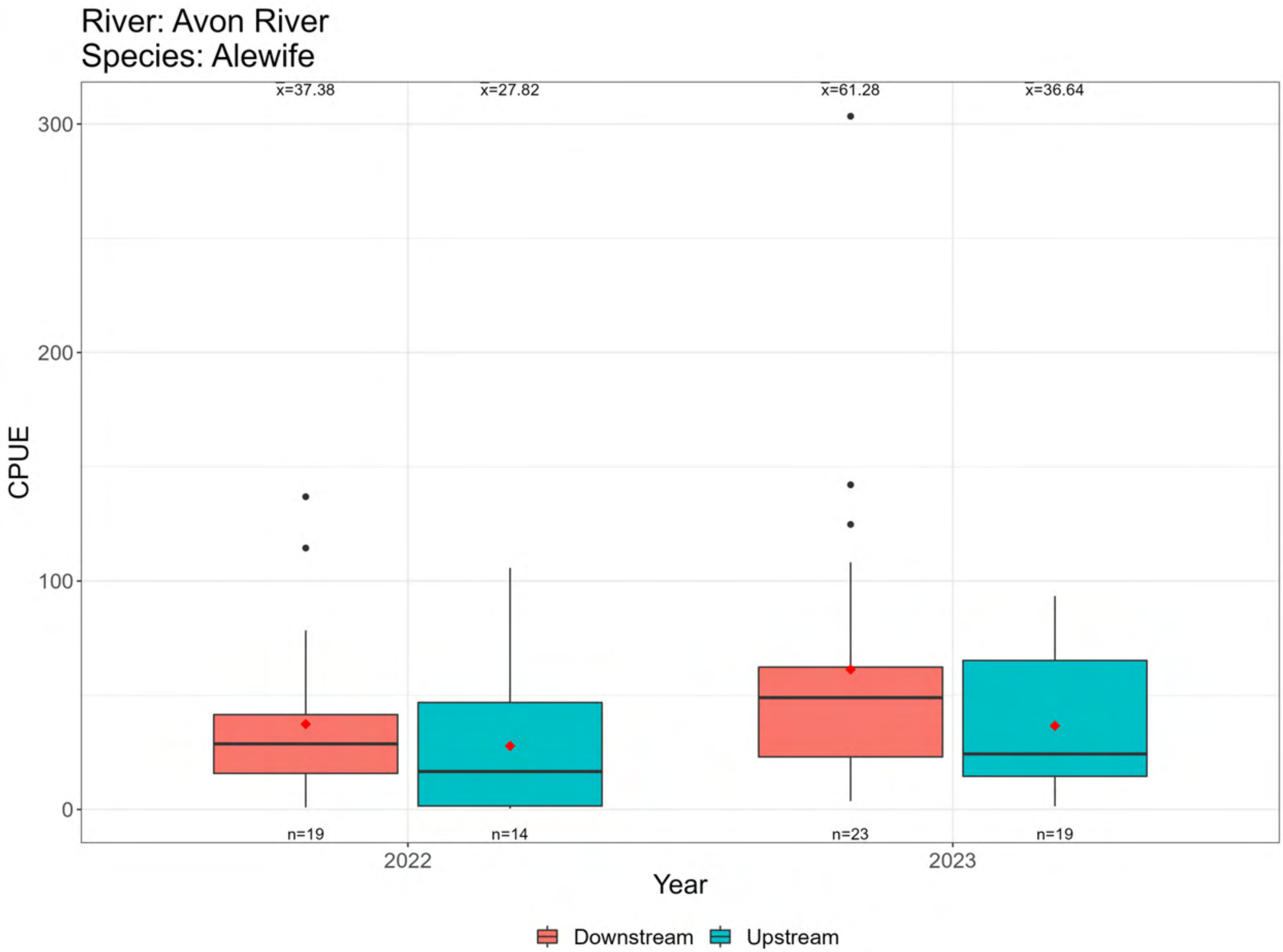

River: Avon River
Species: American Eel
x̄=4.43 x̄=2.86 x̄=4.87 x̄=1.39 x̄=5.6 x̄=3.2 x̄=10.02 x̄=2.22 x̄=11.51 x̄=4.55 x̄=3.99 x̄=2.39 x̄=2.93 x̄=2.24
60
40
20
0
CPUE
n=48 n=43 n=34 n=30 n=34 n=51 n=33 n=16 n=47 n=20 n=66 n=57 n=58 n=40
2017
2018
2019
2020
2021
2022
2023
Year
Downstream
Upstream

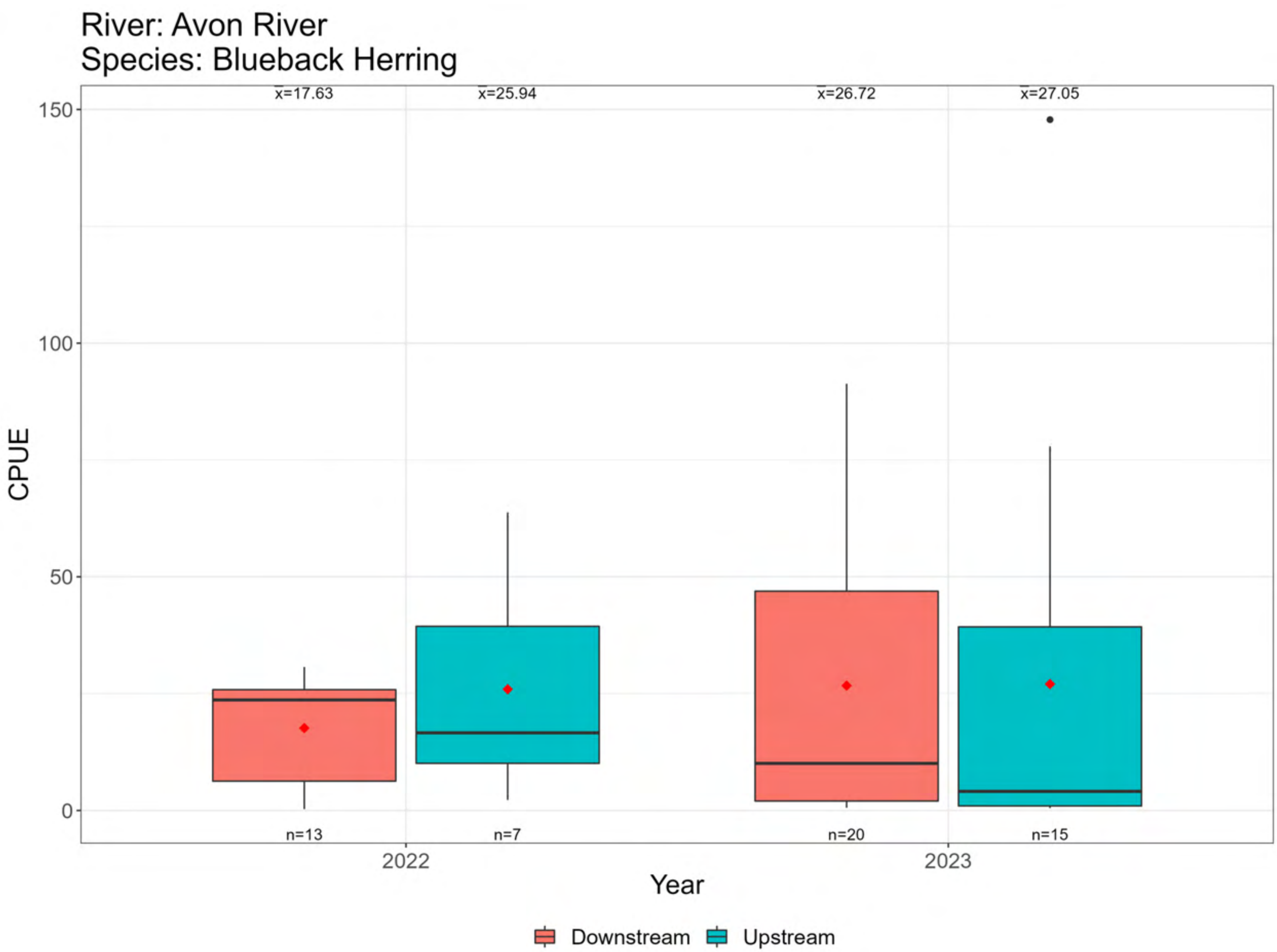

River: Avon River
Species: Atlantic Menhaden
x=0.41
x=14.48
x=0.77
x=6.58
50
40
30
20
10
0
CPUE
n=1
n=18
n=1
n=3
2021
2022
2023
Year
Downstream
Upstream

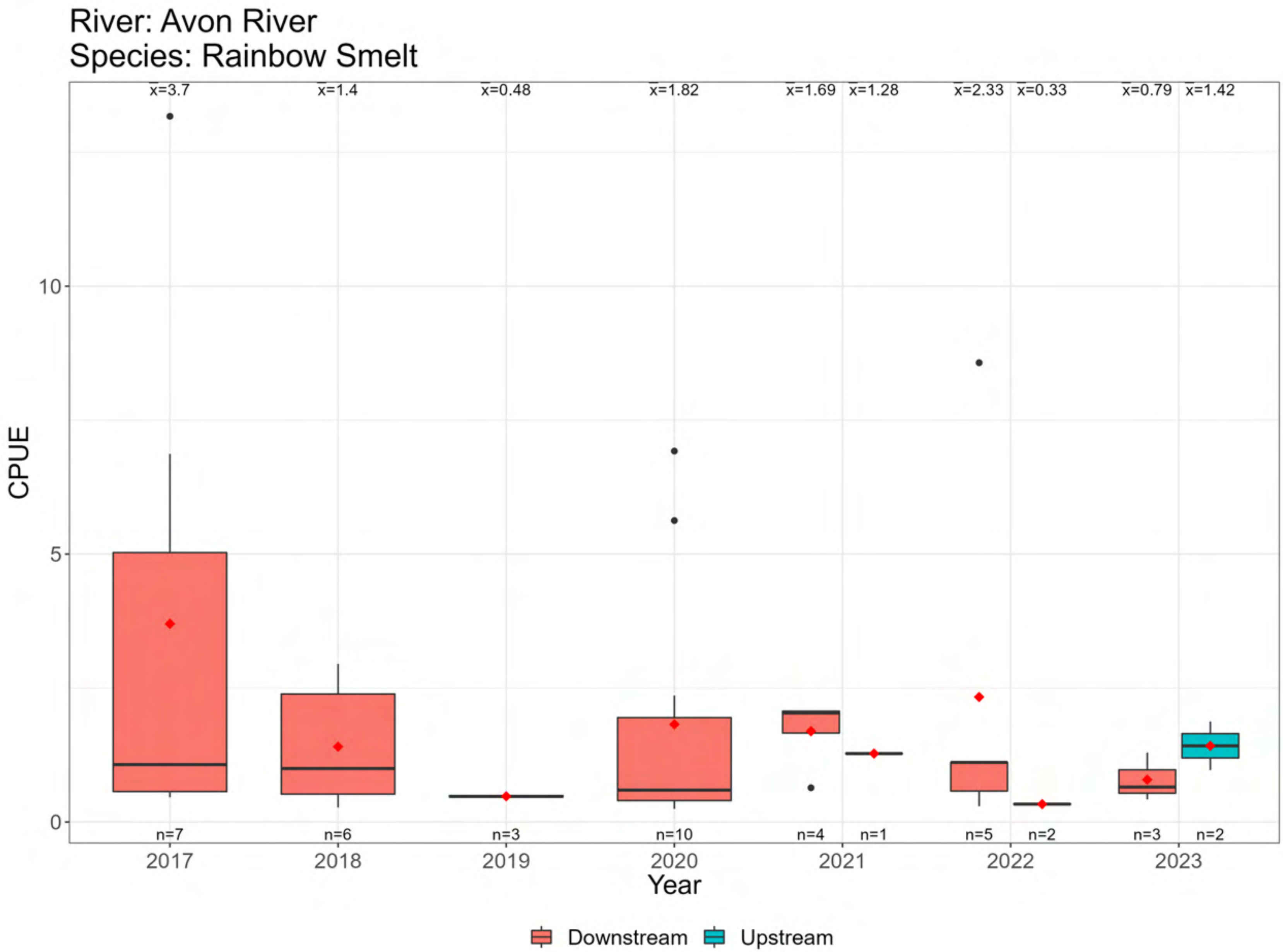

River: Avon River
Species: Atlantic Tomcod
x=4.36
x=0.32
x=1.73
x=15.1
x=0.63
x=4.89
x=0.56
x=13.31
x=2.73
x=13.43
x=5.18
x=11.68
x=1.74
CPUE
80
60
40
20
0
n=18
n=9
n=22
n=40
n=8
n=30
n=6
n=29
n=18
n=57
n=37
n=74
n=39
2017
2018
2019
2020
2021
2022
2023
Year
Downstream
Upstream

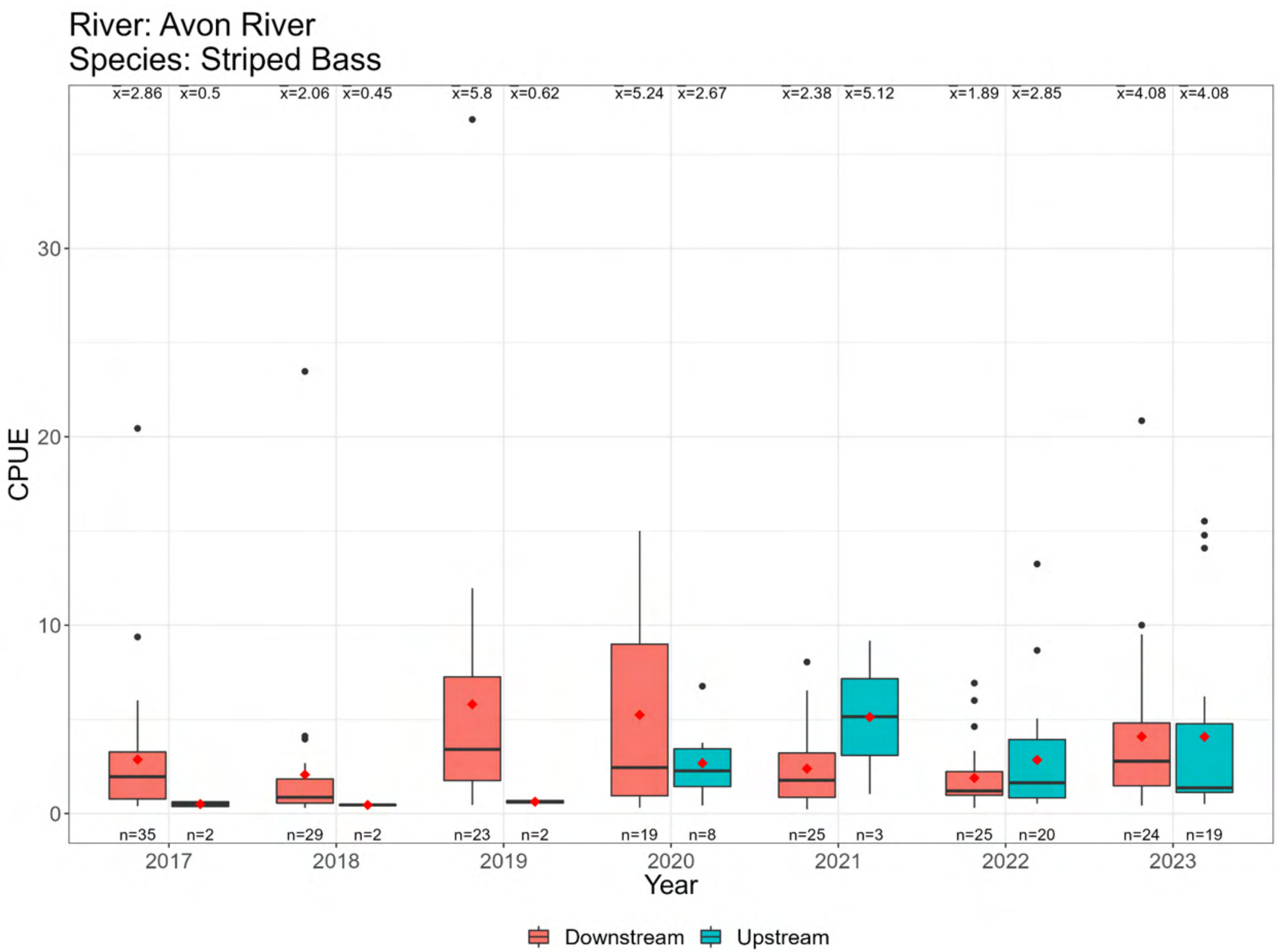


River: Avon River
Species: Gaspereau
x̄=73.2 x̄=27.76
x̄=66.91 x̄=17.79
x̄=26.7 x̄=8.03
x̄=60.6 x̄=53.37
x̄=36.63 x̄=56.4
x̄=20.7 x̄=20.81
x̄=32.85 x̄=25.83
400
300
200
100
0
CPUE
n=25 n=14
n=29 n=12
n=24 n=19
n=37 n=22
n=21 n=8
n=59 n=36
n=63 n=47
2017
2018
2019
2020
2021
2022
2023
Year
Downstream
Upstream


River: Avon River
Species: Alewife
x̄=37.38
x̄=27.82
x̄=61.28
x̄=36.64
300
200
100
0
CPUE
n=19
n=14
n=23
n=19
2022
2023
Year
Downstream
Upstream


River: Avon River
Species: Blueback Herring
x̄=17.63
x̄=25.94
x̄=26.72
x̄=27.05
150
100
50
0
CPUE
n=13
n=7
n=20
n=15
2022
2023
Year
Downstream
Upstream


River: Avon River
Species: Rainbow Smelt
x=3.7
x=1.4
x=0.48
x=1.82
x=1.69
x=1.28
x=2.33
x=0.33
x=0.79
x=1.42
CPUE
10
5
0
n=7
n=6
n=3
n=10
n=4
n=1
n=5
n=2
n=3
n=2
2017
2018
2019
2020
2021
2022
2023
Year
Downstream
Upstream

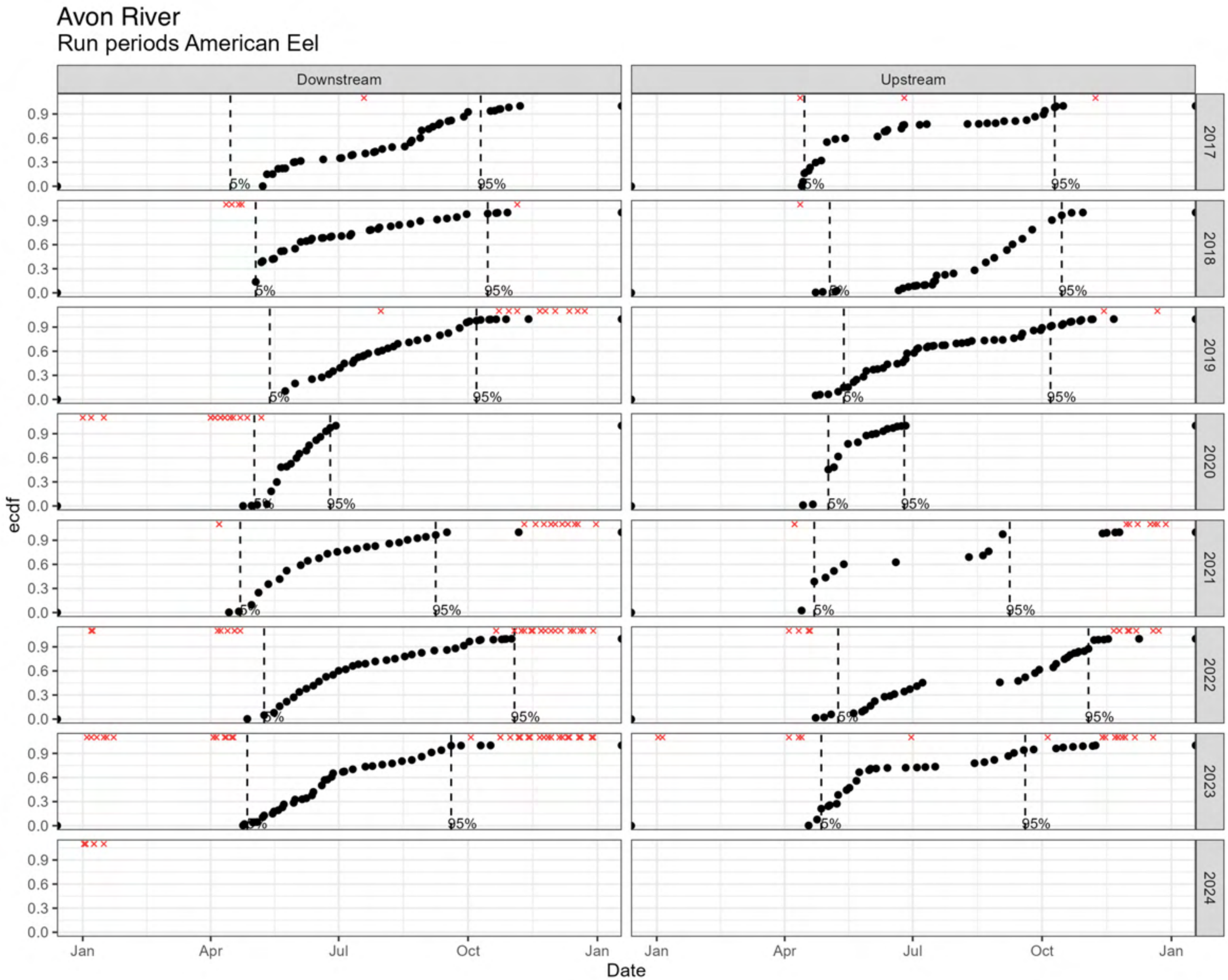


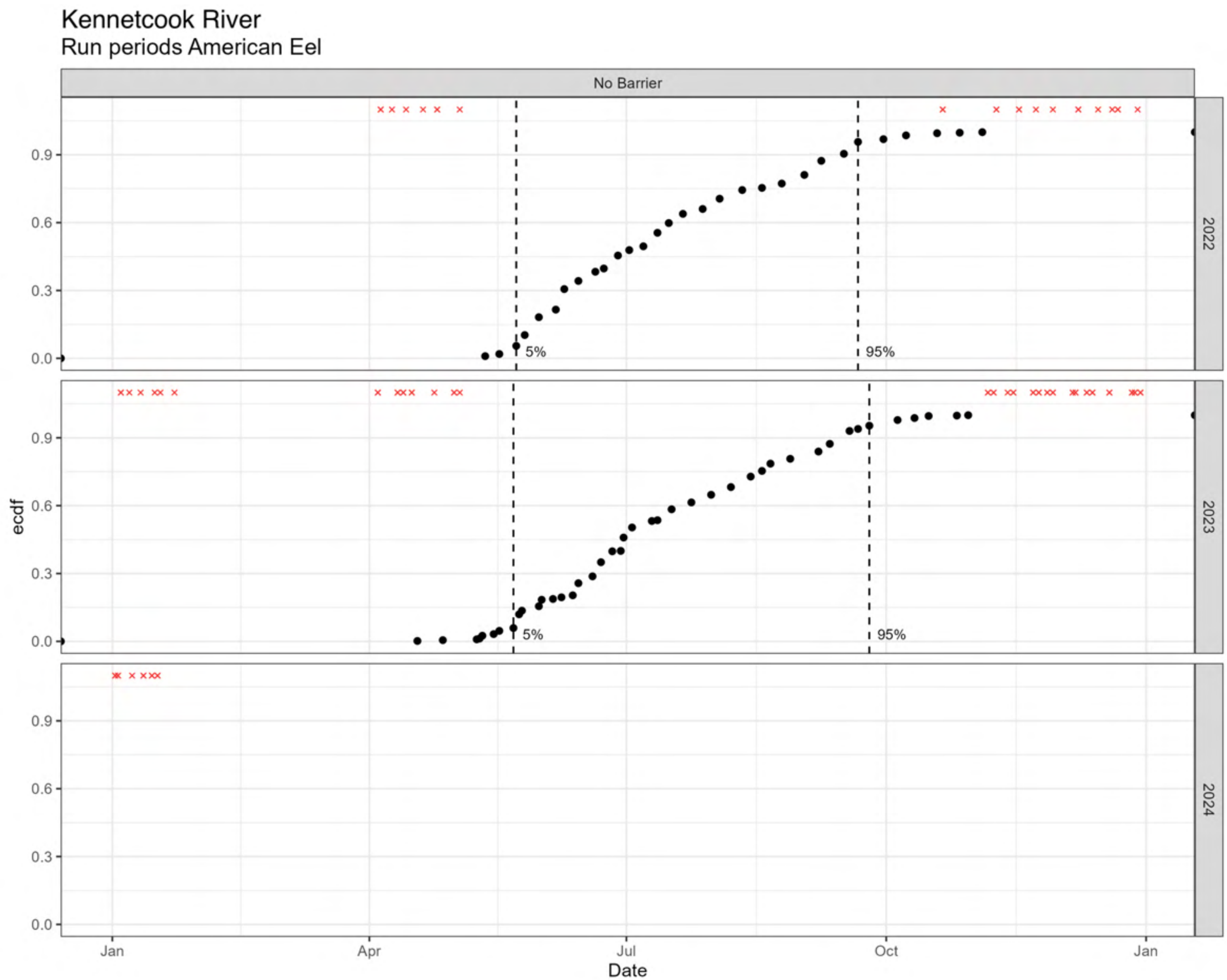
River: Avon River
Species: Striped Bass
x=2.86
x=0.5
x=2.06
x=0.45
x=5.8
x=0.62
x=5.24
x=2.67
x=2.38
x=5.12
x=1.89
x=2.85
x=4.08
x=4.08
CPUE
30
20
10
0
n=35
n=2
n=29
n=2
n=23
n=2
n=19
n=8
n=25
n=3
n=25
n=20
n=24
n=19
2017
2018
2019
2020
2021
2022
2023
Year
Downstream
Upstream

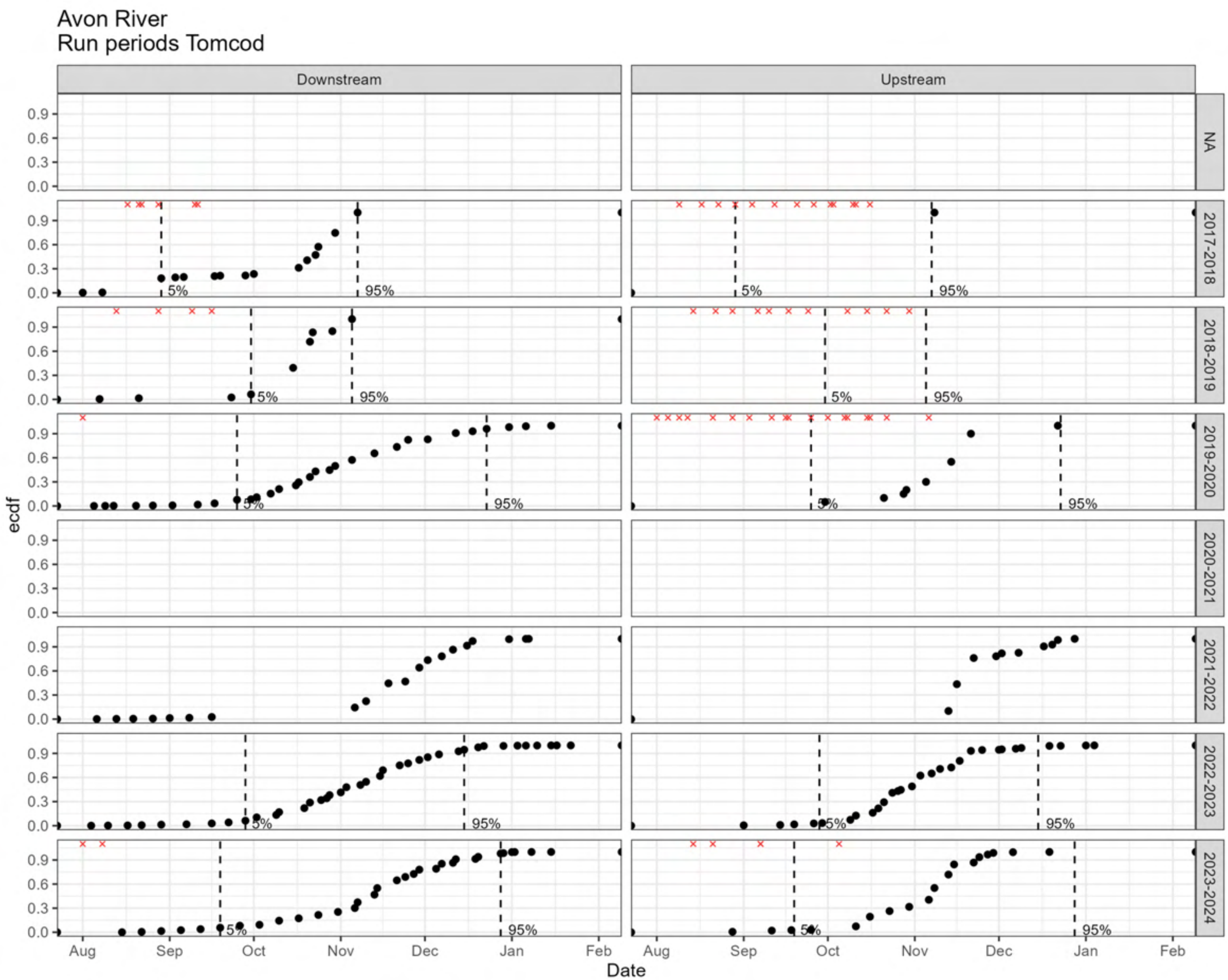
Appendix F - Comparison of Migration Windows by Species

Red x's indicate dates when fishing events occurred, but the specified species was NOT caught.

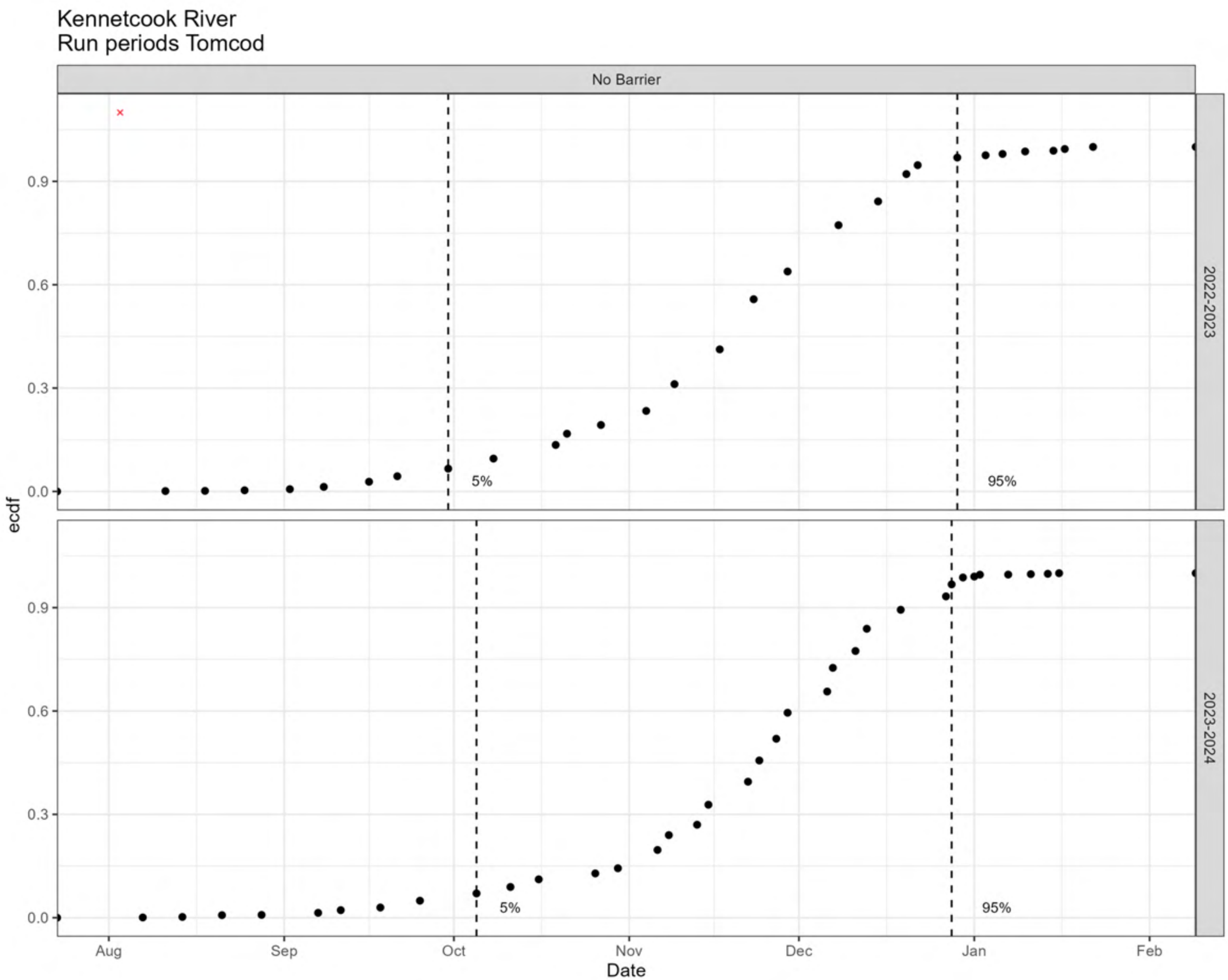
The cumulative CPUE data is scaled relative from 0 to 1 and plotted in increments over time where 0 indicates 0% of the cumulative CPUE recorded over the given time period and 1 being 100% of the cumulative CPUE for the given time period. The date at which 5% and 95% of the cumulative CPUE has been recorded for the given time period is marked, which is defined as the "run time".


Avon River
Run periods American Eel
Downstream
Upstream
2017
2018
2019
2020
2021
2022
2023
2024
0.0
0.3
0.6
0.9
5%
95%
ecdf
Jan
Apr
Jul
Oct
Jan
Date

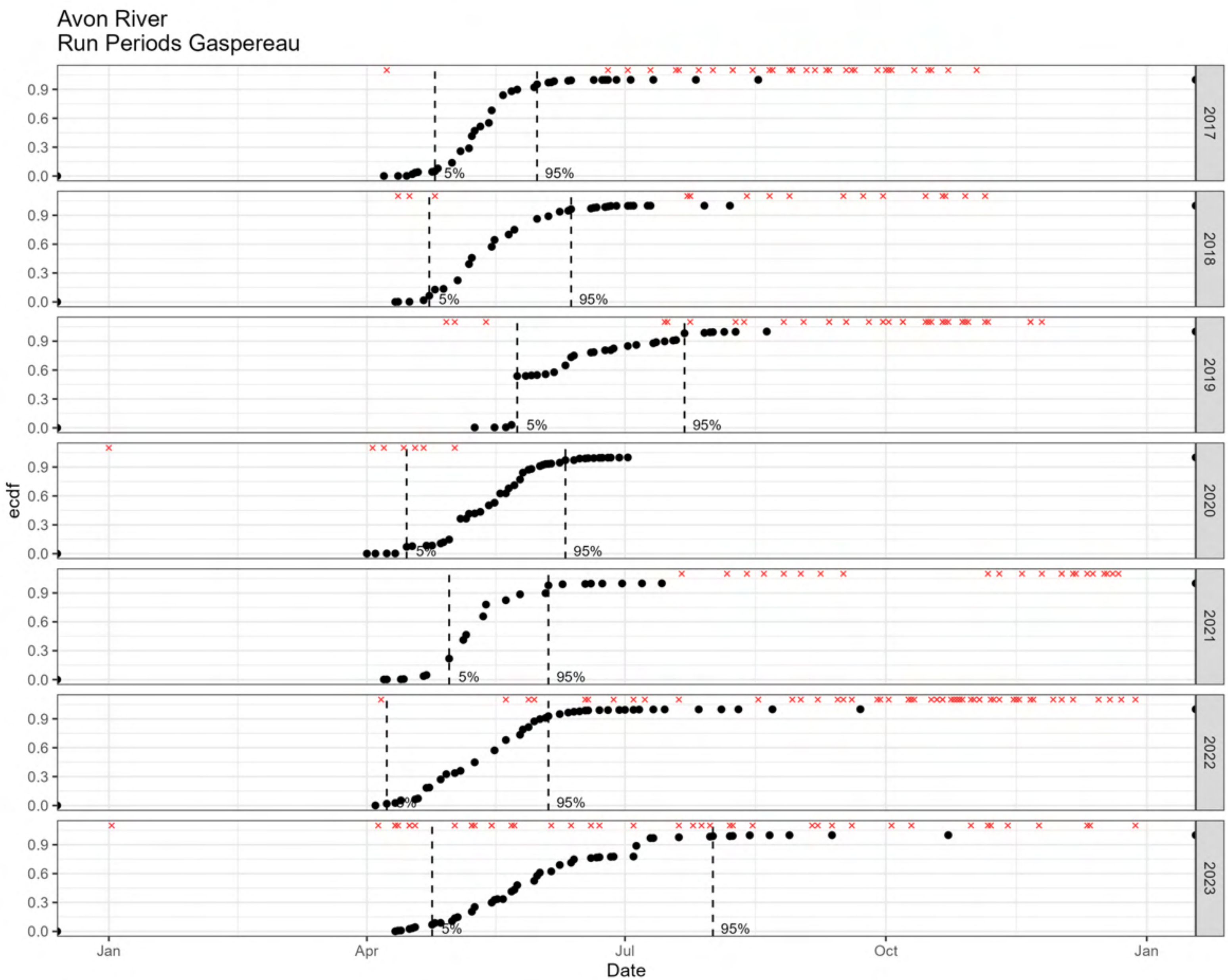

Kennetcook River
Run periods American Eel
No Barrier
2022
2023
2024
ecdf
0.0
0.3
0.6
0.9
5%
95%
Jan
Apr
Jul
Oct
Jan
Date



Avon River
Run periods Tomcod
Downstream
Upstream
NA
2017-2018
2018-2019
2019-2020
2020-2021
2021-2022
2022-2023
2023-2024
ecdf
0.0
0.3
0.6
0.9
5%
95%
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

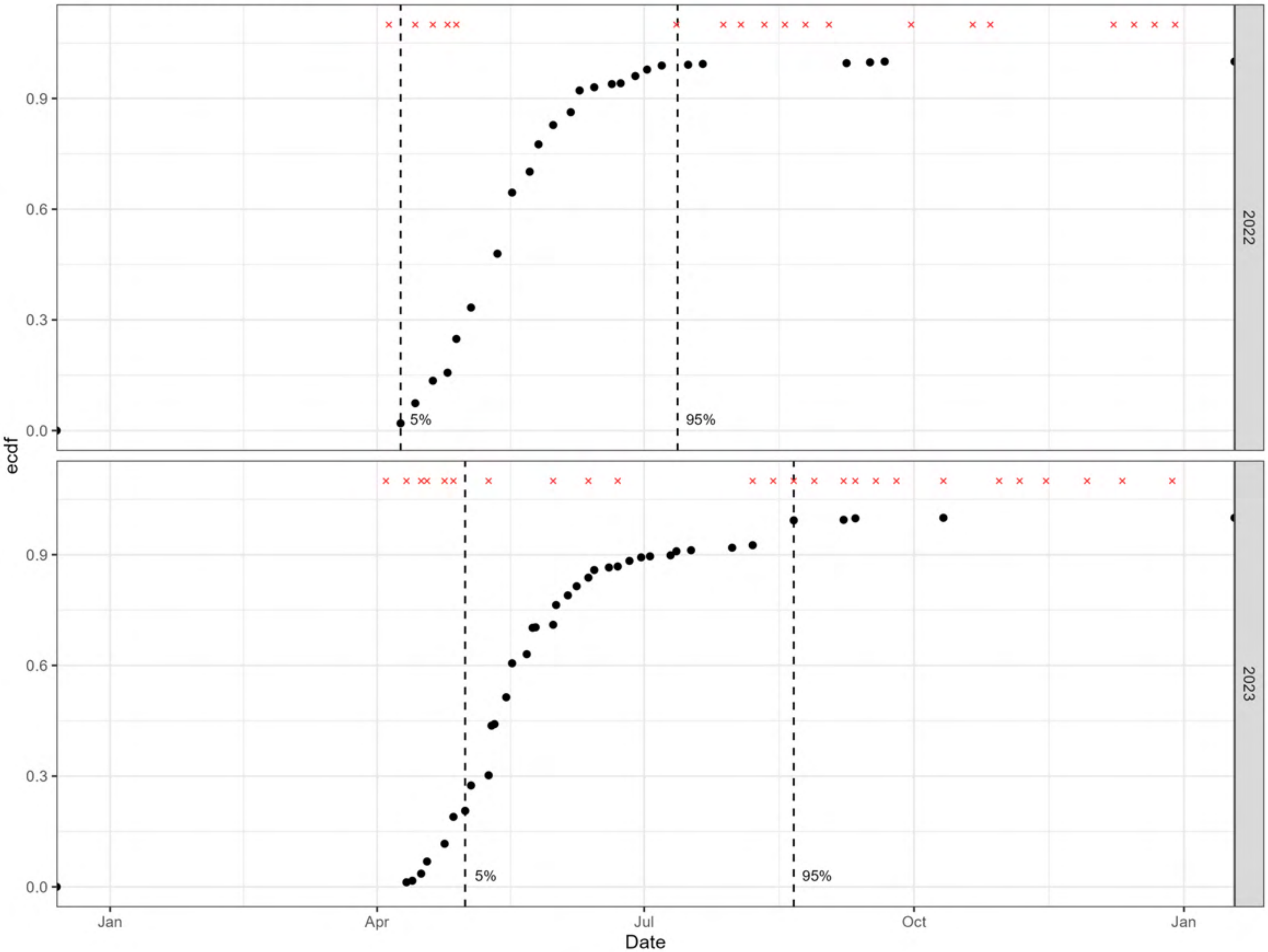


Kennetcook River
Run periods Tomcod
No Barrier
2022-2023
2023-2024
5%
95%
ecdf
0.0
0.3
0.6
0.9
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

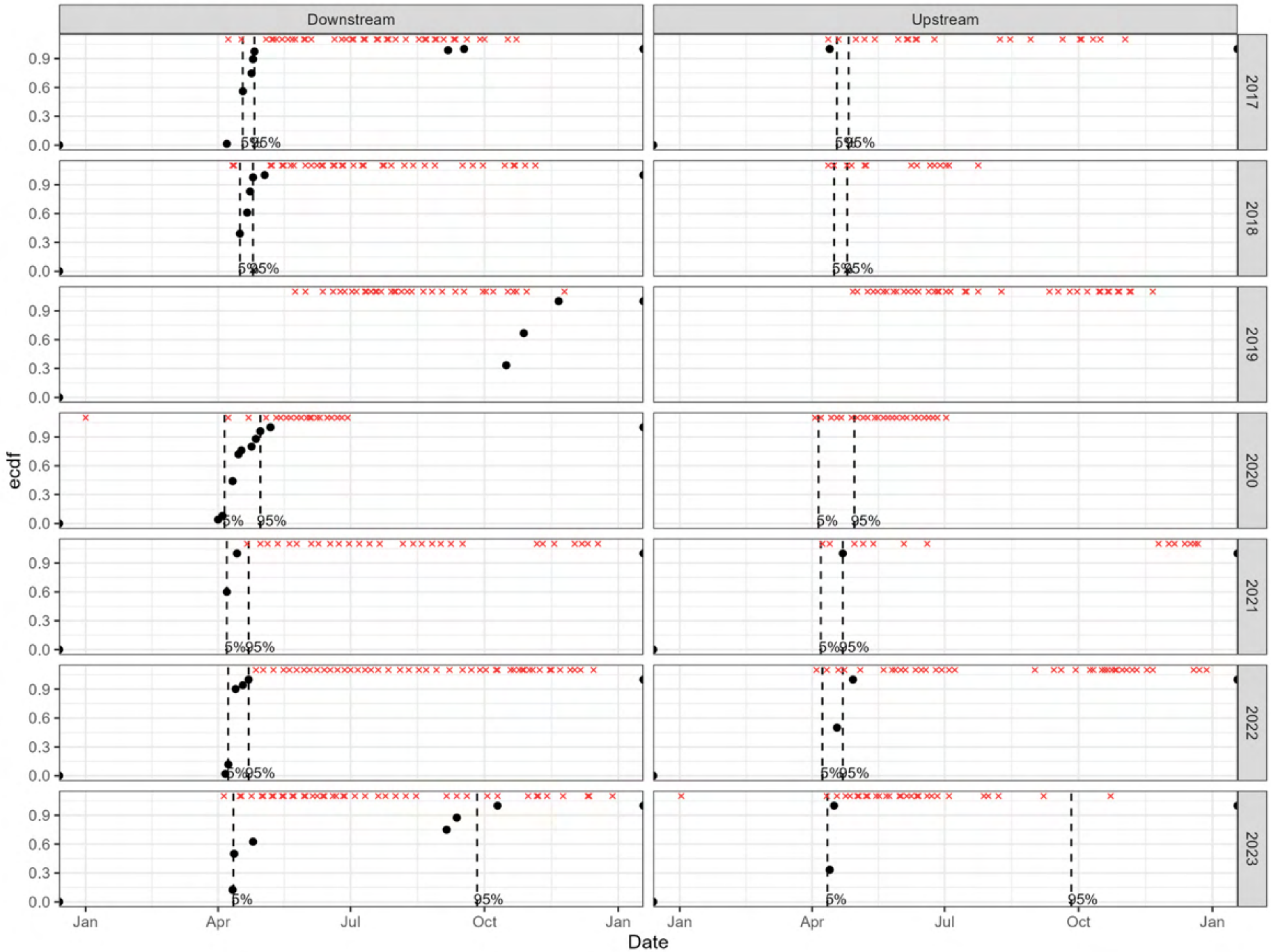


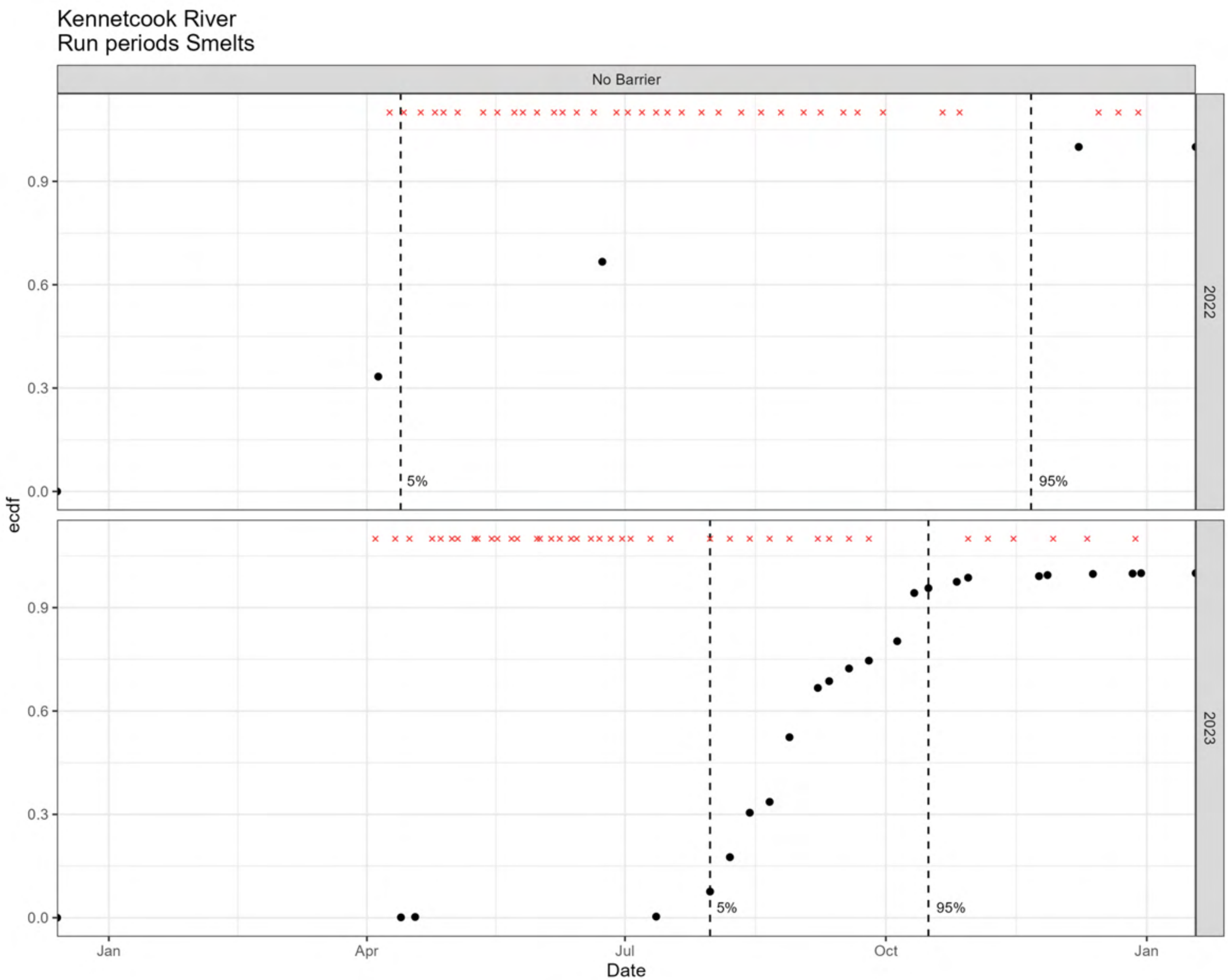
Avon River
Run Periods Gaspereau
ecdf
0.0
0.3
0.6
0.9
5%
95%
2017
2018
2019
2020
2021
2022
2023
Jan
Apr
Jul
Oct
Jan
Date

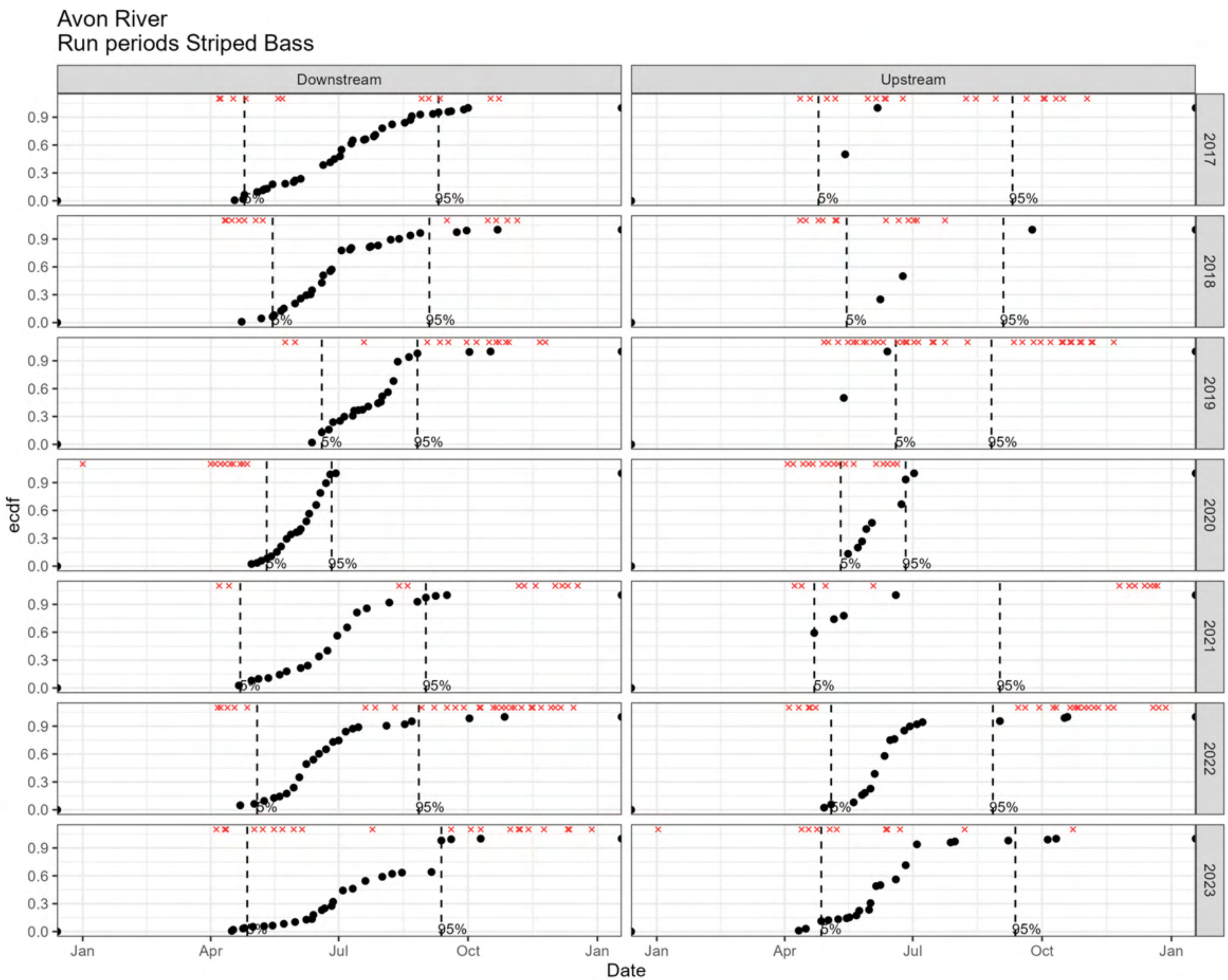
Kennetcook River
Run Periods Gaspereau



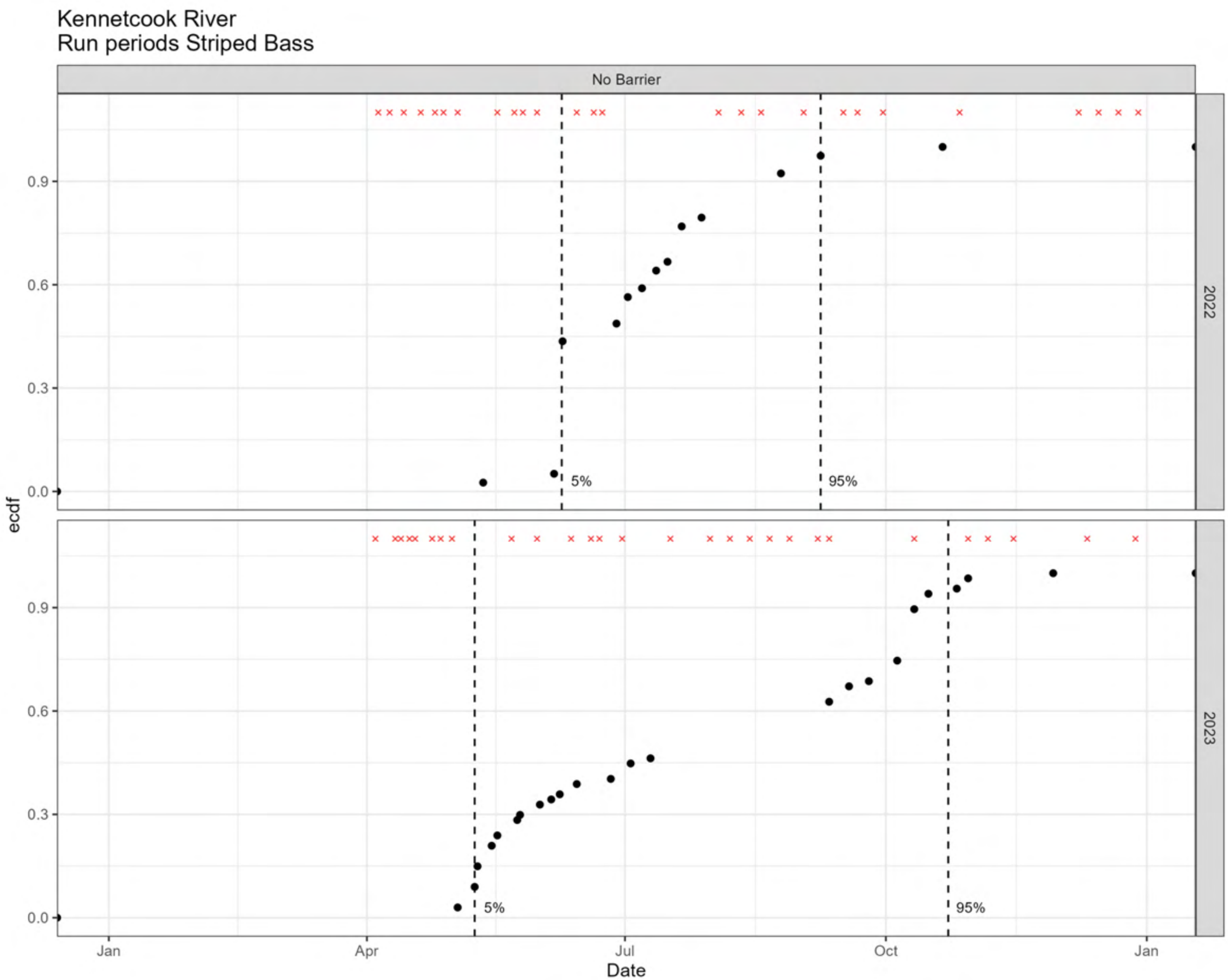
Avon River
Run periods Smelts




Kennetcook River
Run periods Smelts
No Barrier
2022
2023
ecdf
0.0
0.3
0.6
0.9
5%
95%
Jan
Apr
Jul
Oct
Date



Avon River
Run periods Striped Bass
Downstream
Upstream
2017
2018
2019
2020
2021
2022
2023
ecdf
0.0
0.3
0.6
0.9
5%
95%
Jan
Apr
Jul
Oct
Jan
Date


Kennetcook River
Run periods Striped Bass
No Barrier
2022
2023
5%
95%
ecdf
0.0
0.3
0.6
0.9
Jan
Apr
Jul
Oct
Jan
Date

Appendix G – Acoustic Trial

Report provided by Innovasea (Dale Webber) based on deployments of HR2 and HR3 receivers (and compatible test tags) downstream of the Avon causeway in January 2024.

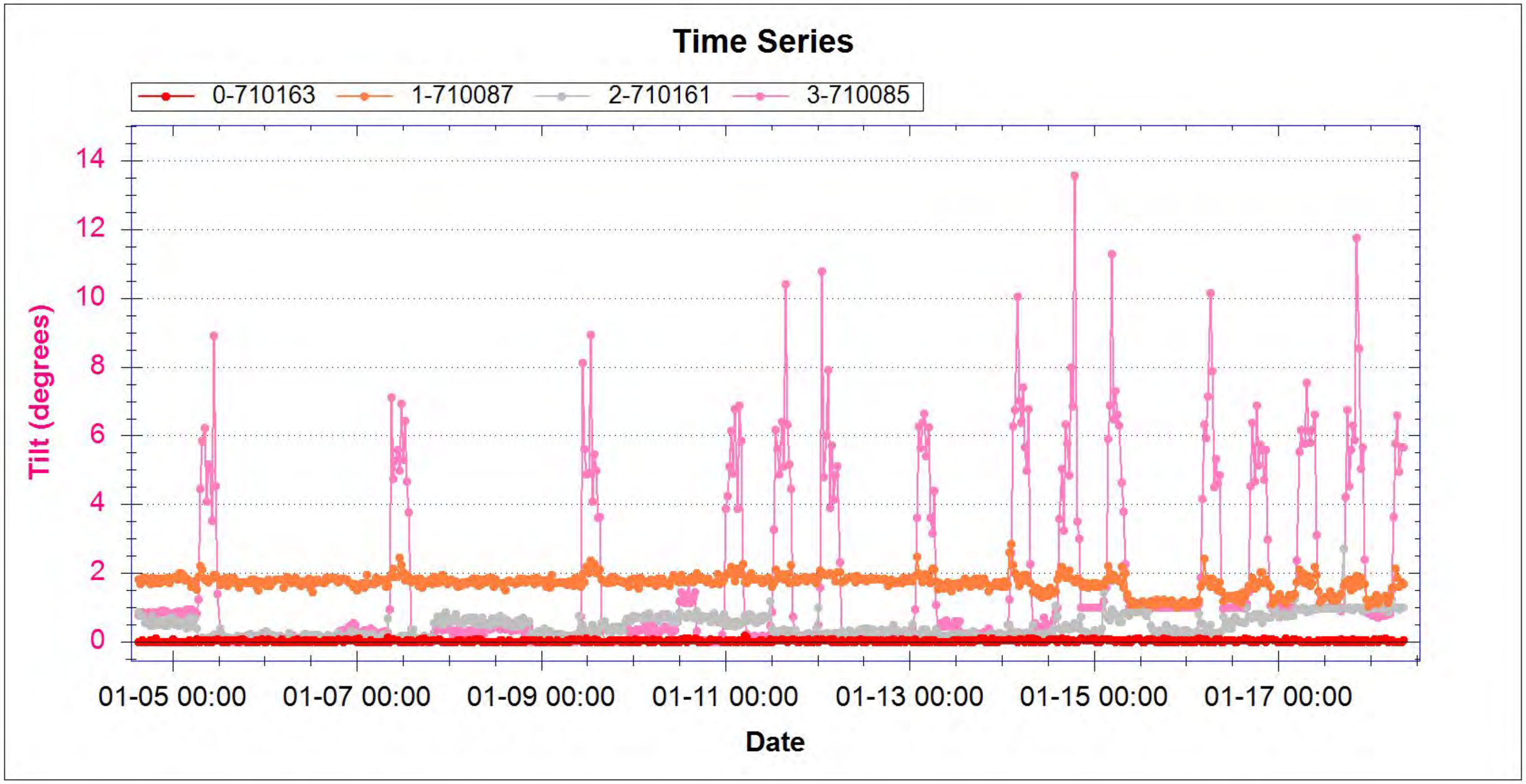
Windsor Tests – 180 & 307 kHz

March 22, 2024 | Dale Webber


Avon River - Aboiteau
Innovasea
Estuary
St4
St2
Ref 180 tag
St3
St1
Image © 2024 Airbus
Google Earth

307 kHz – HR3s

Tilt – 307 kHz

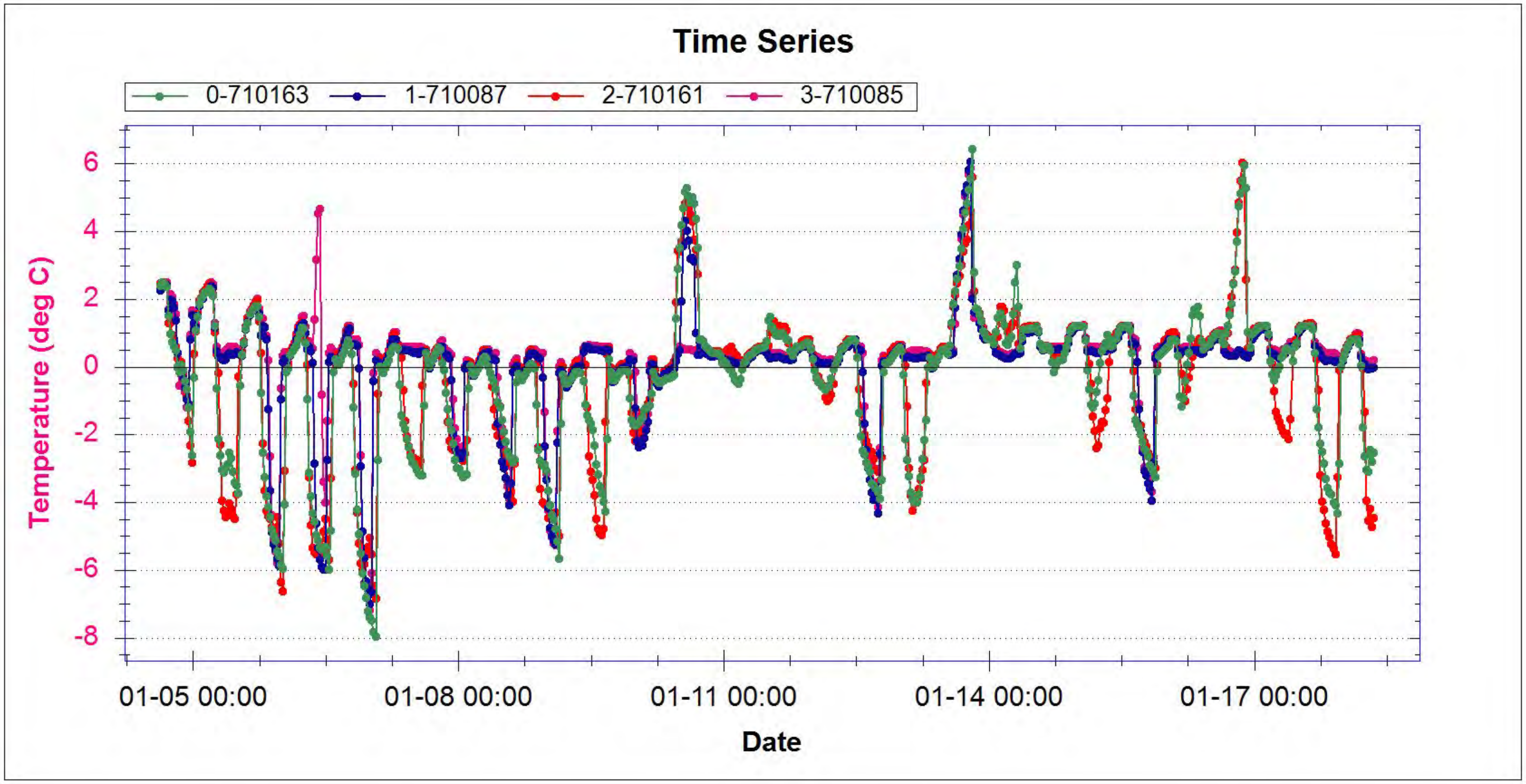


Time Series
0-710163
1-710087
2-710161
3-710085
Tilt (degrees)
14
12
10
8
6
4
2
0
01-05 00:00
01-07 00:00
01-09 00:00
01-11 00:00
01-13 00:00
01-15 00:00
01-17 00:00
Date

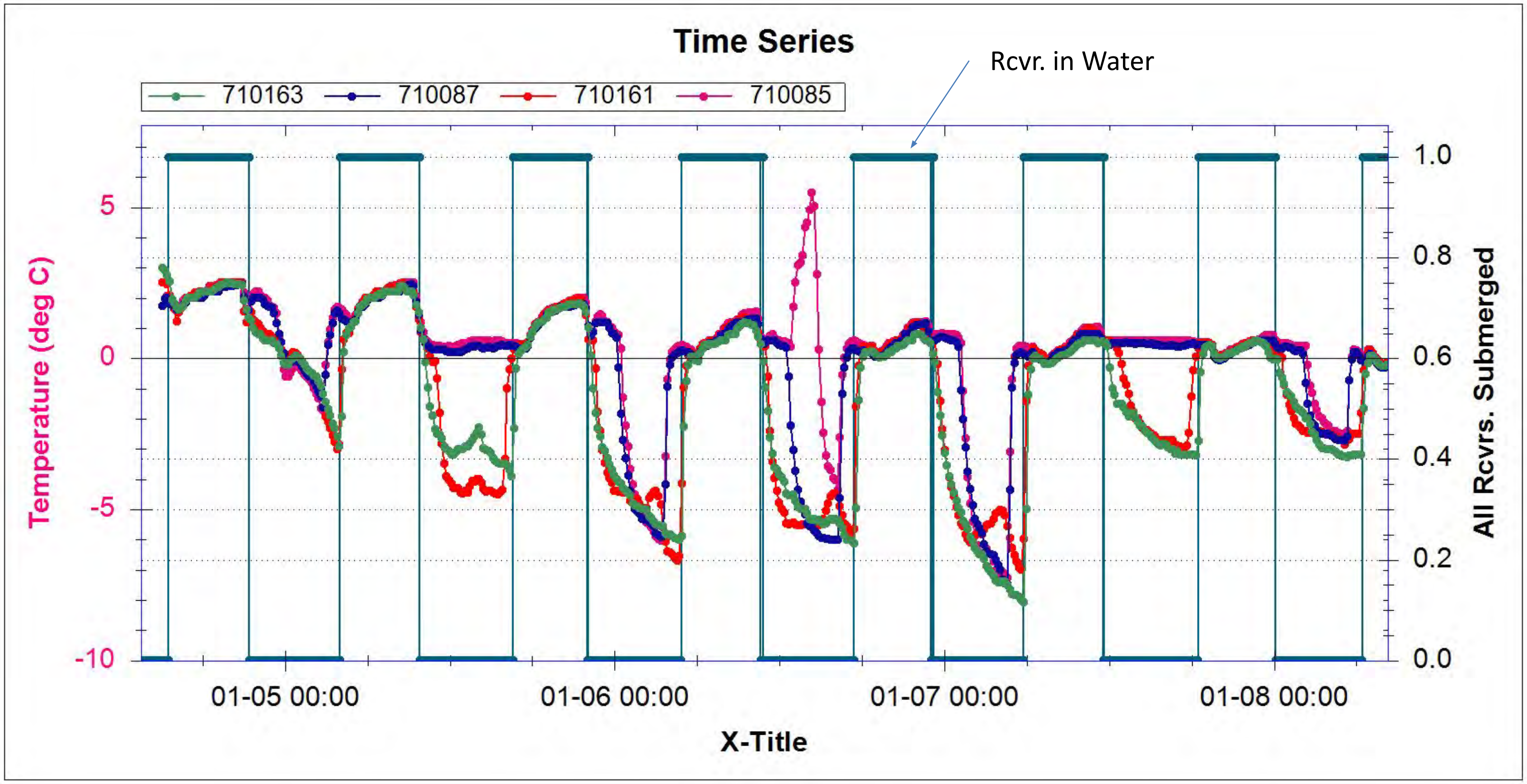
Diagnostics-Noise – 307 kHz

There were no Noise records in the Receiver. I am looking into this

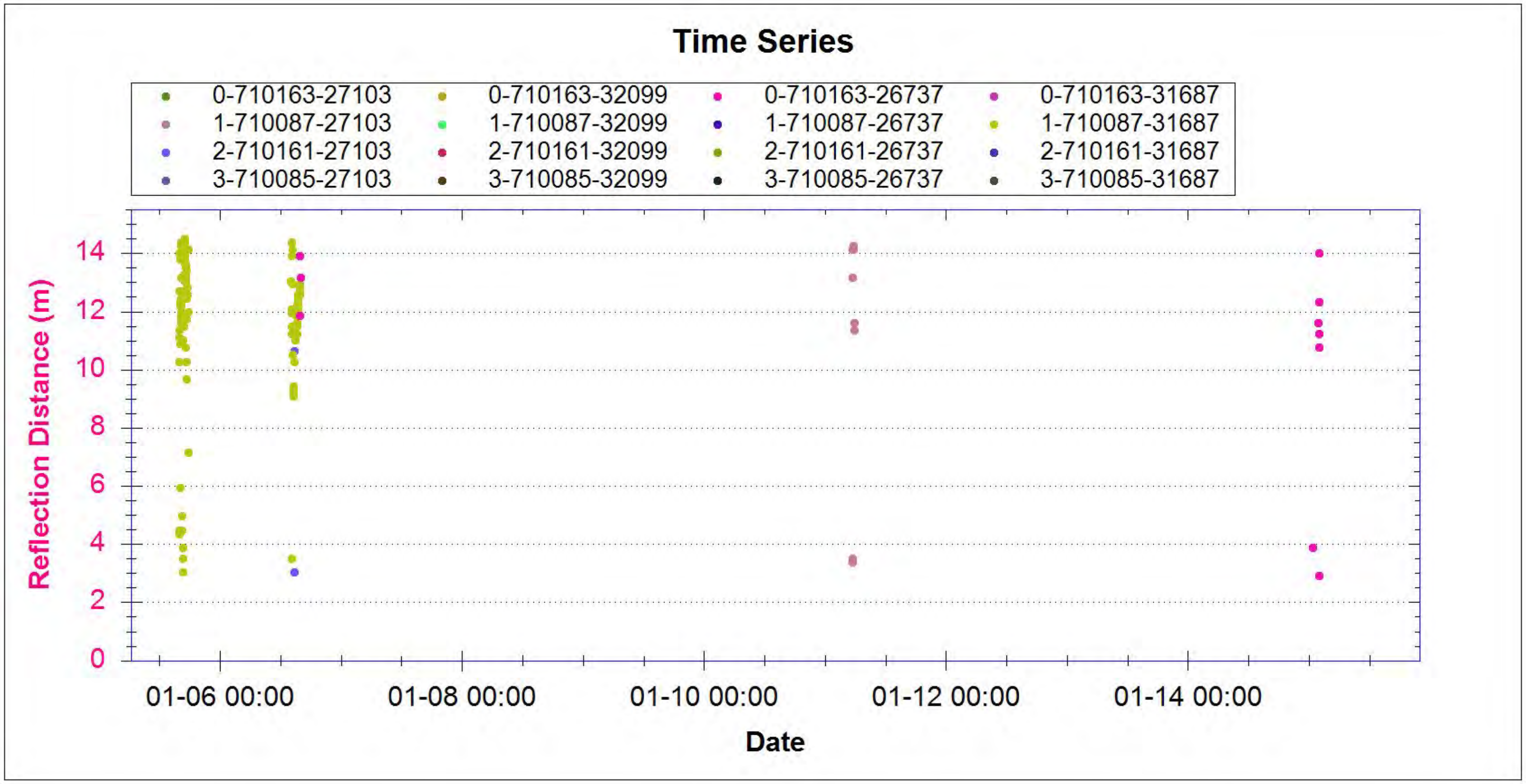
Temperature – 307 kHz



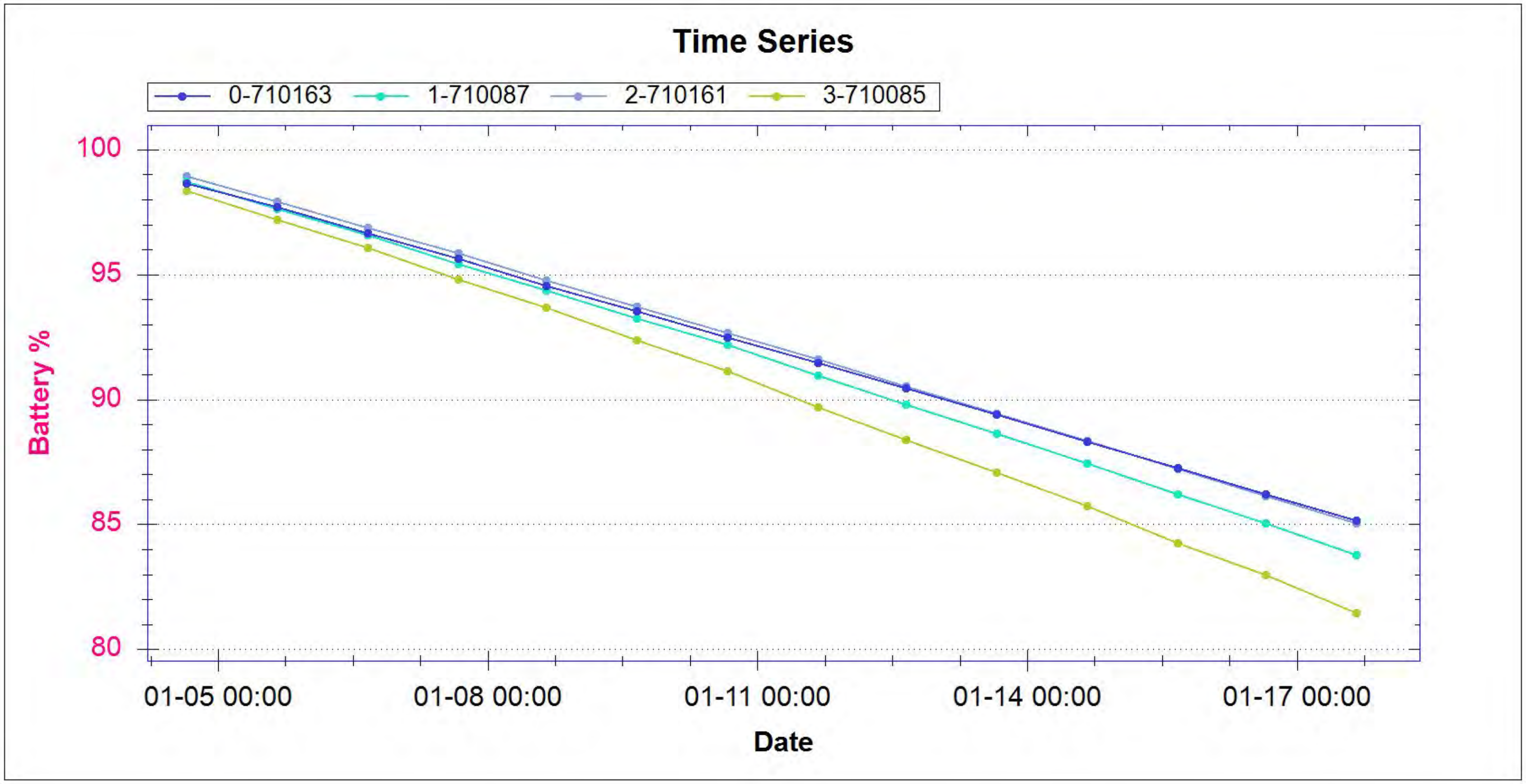
Temperature – 307 kHz



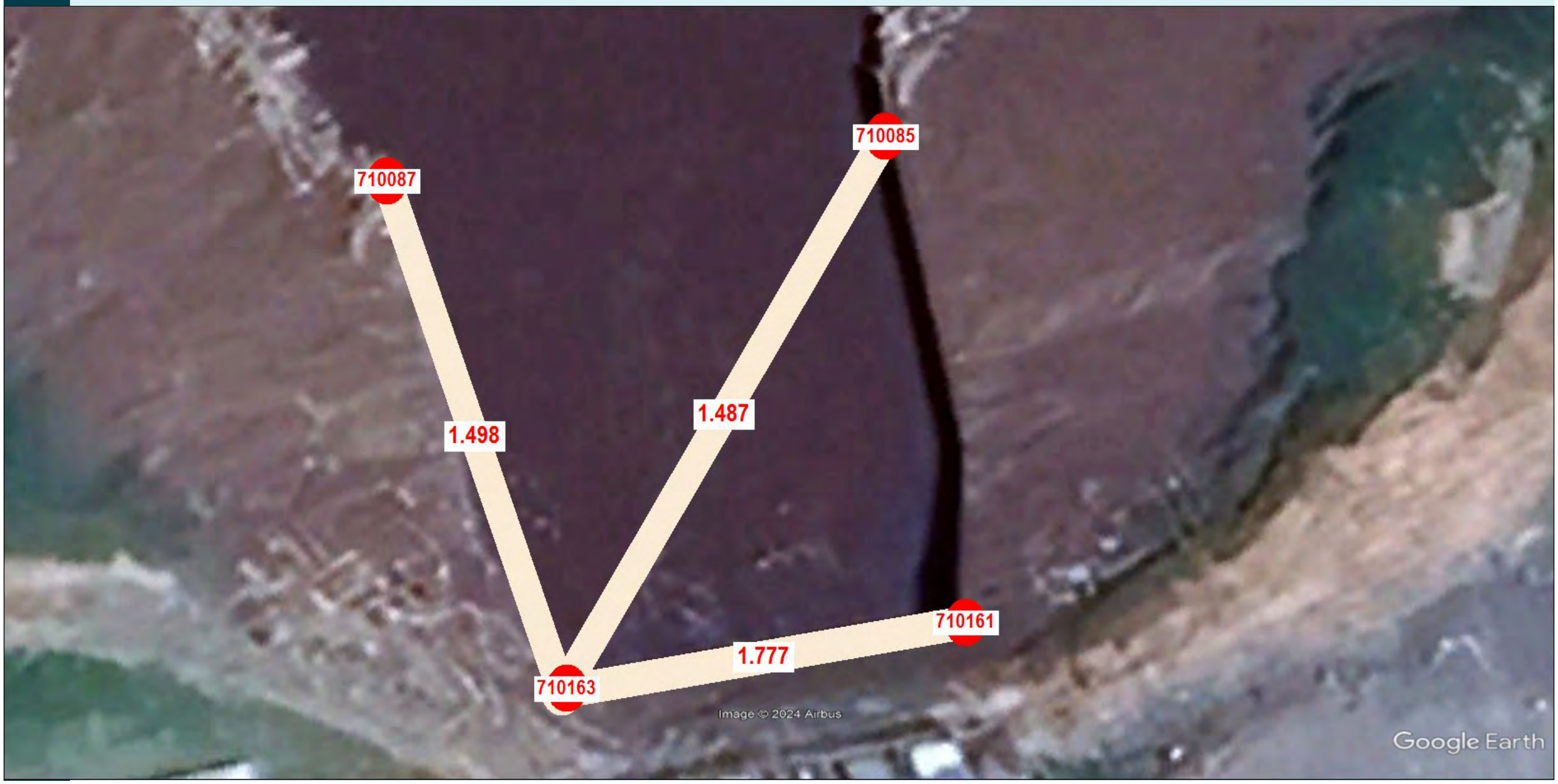
Acoustic Relections – 307 kHz



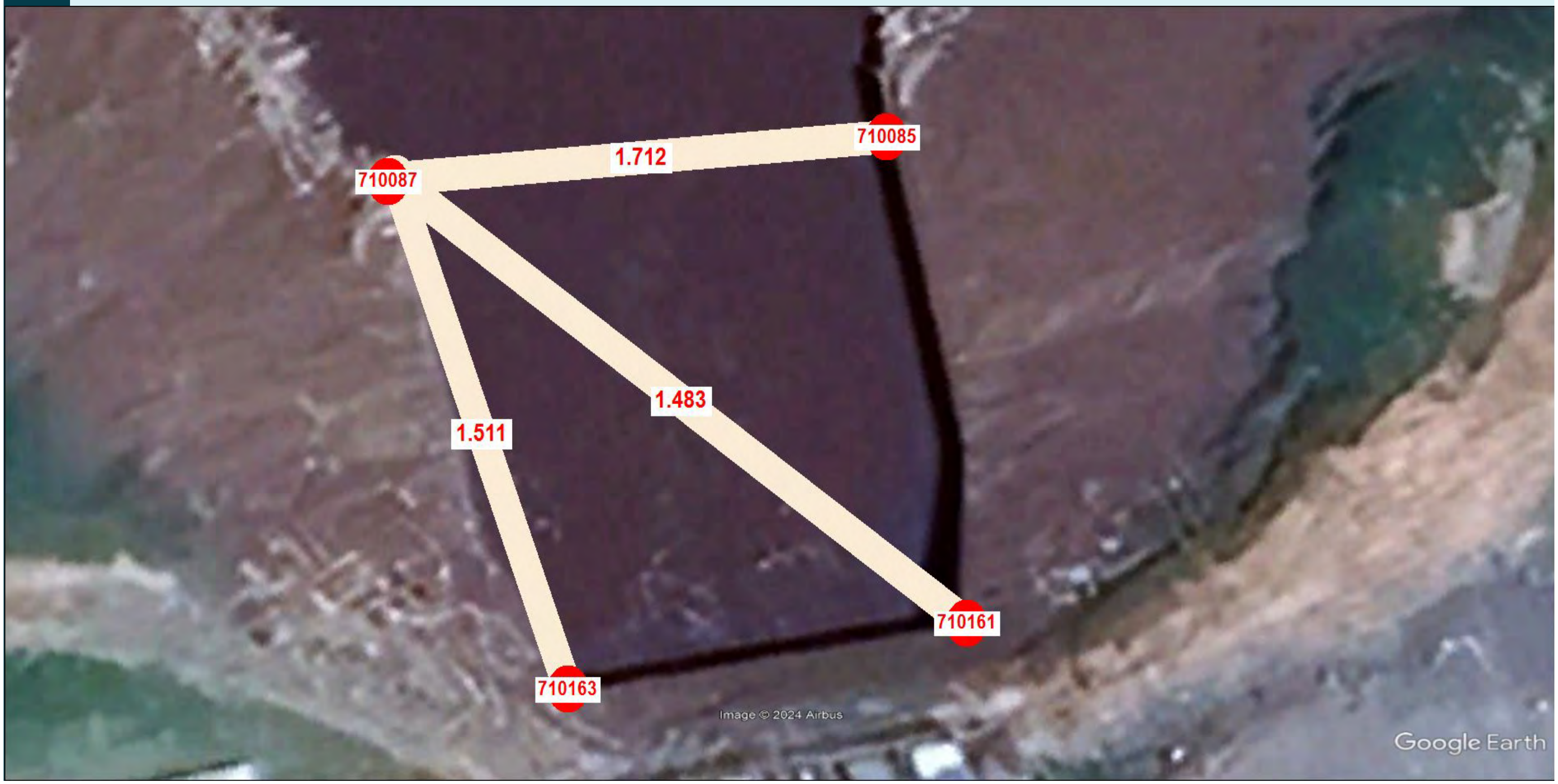
Receiver Battery Level – 307 kHz



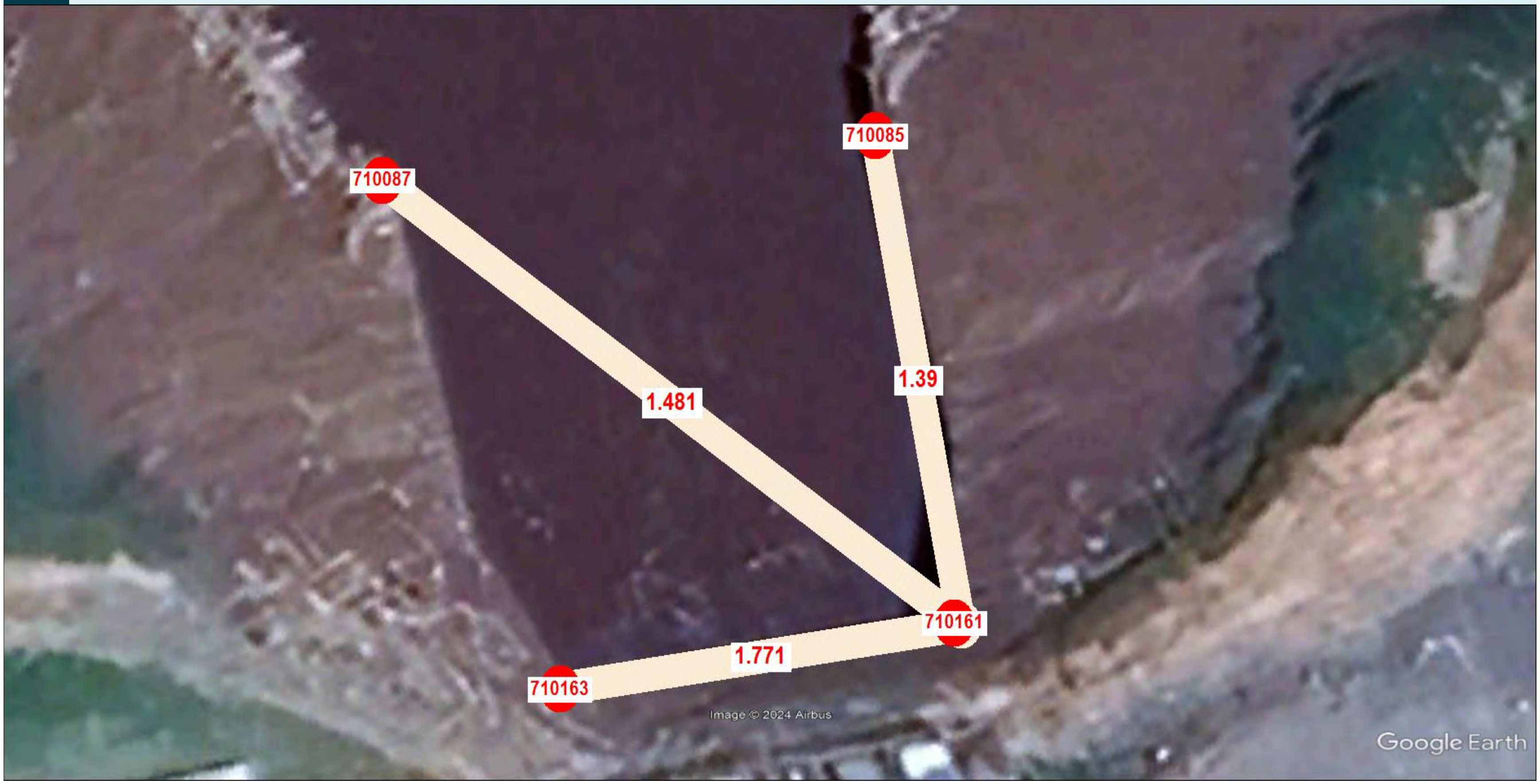
Rcvr. to Rcvr. Detection Performance (average over the trial)



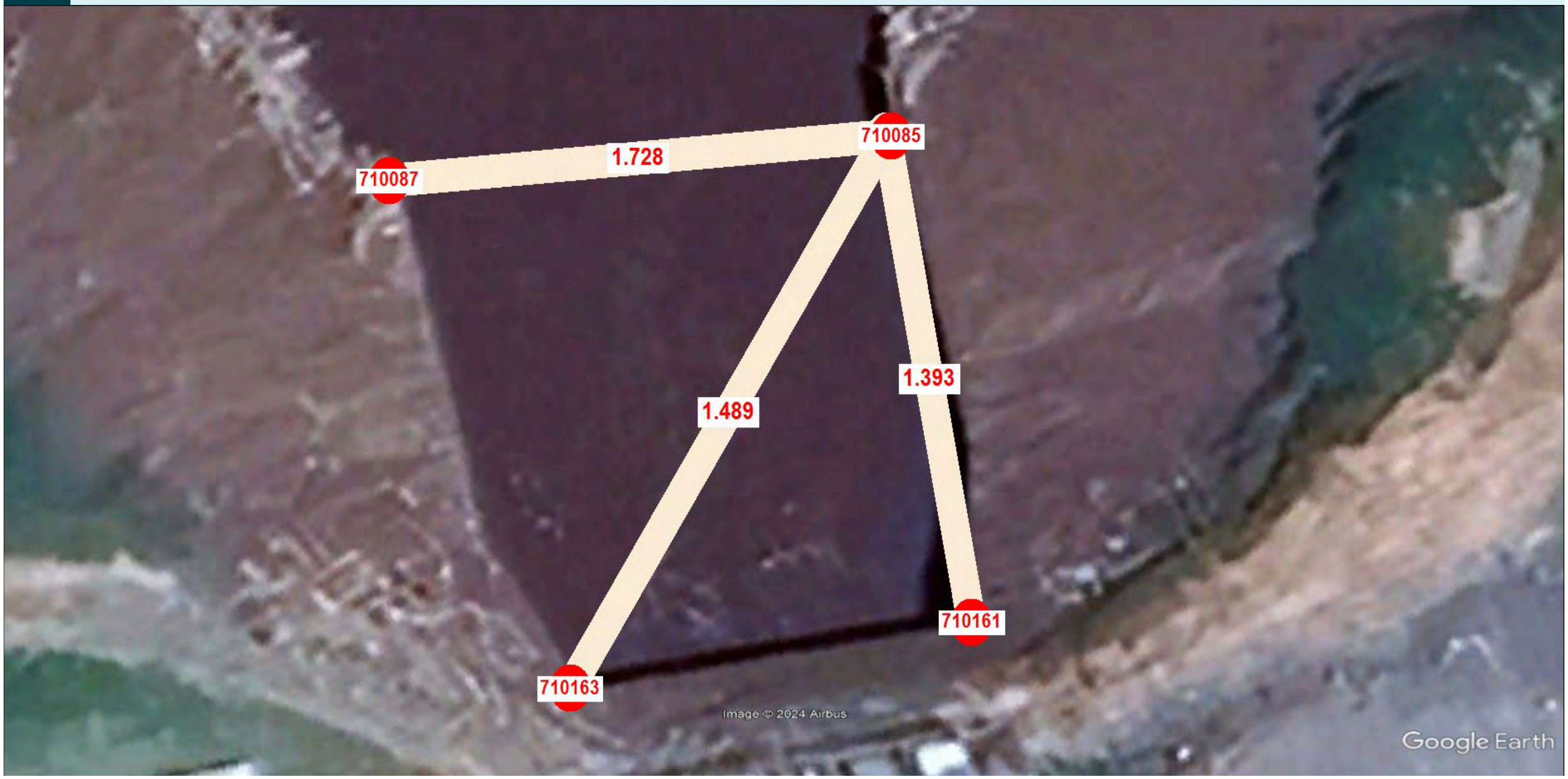
Rcvr. to Rcvr. Detection Performance (average over the trial)



Rcvr. to Rcvr. Detection Performance (average over the trial)

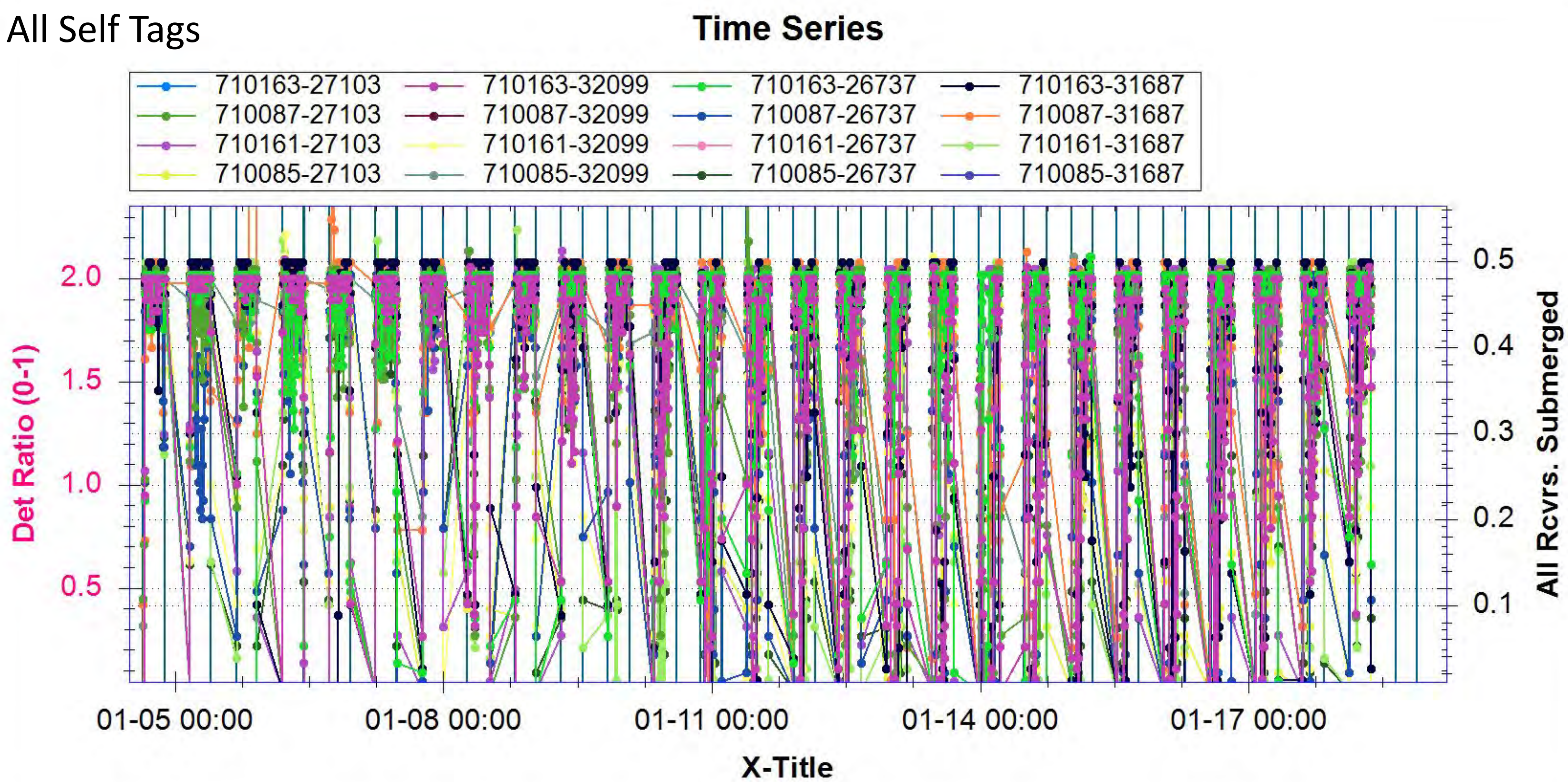


Rcvr. to Rcvr. Detection Performance (average over the trial)



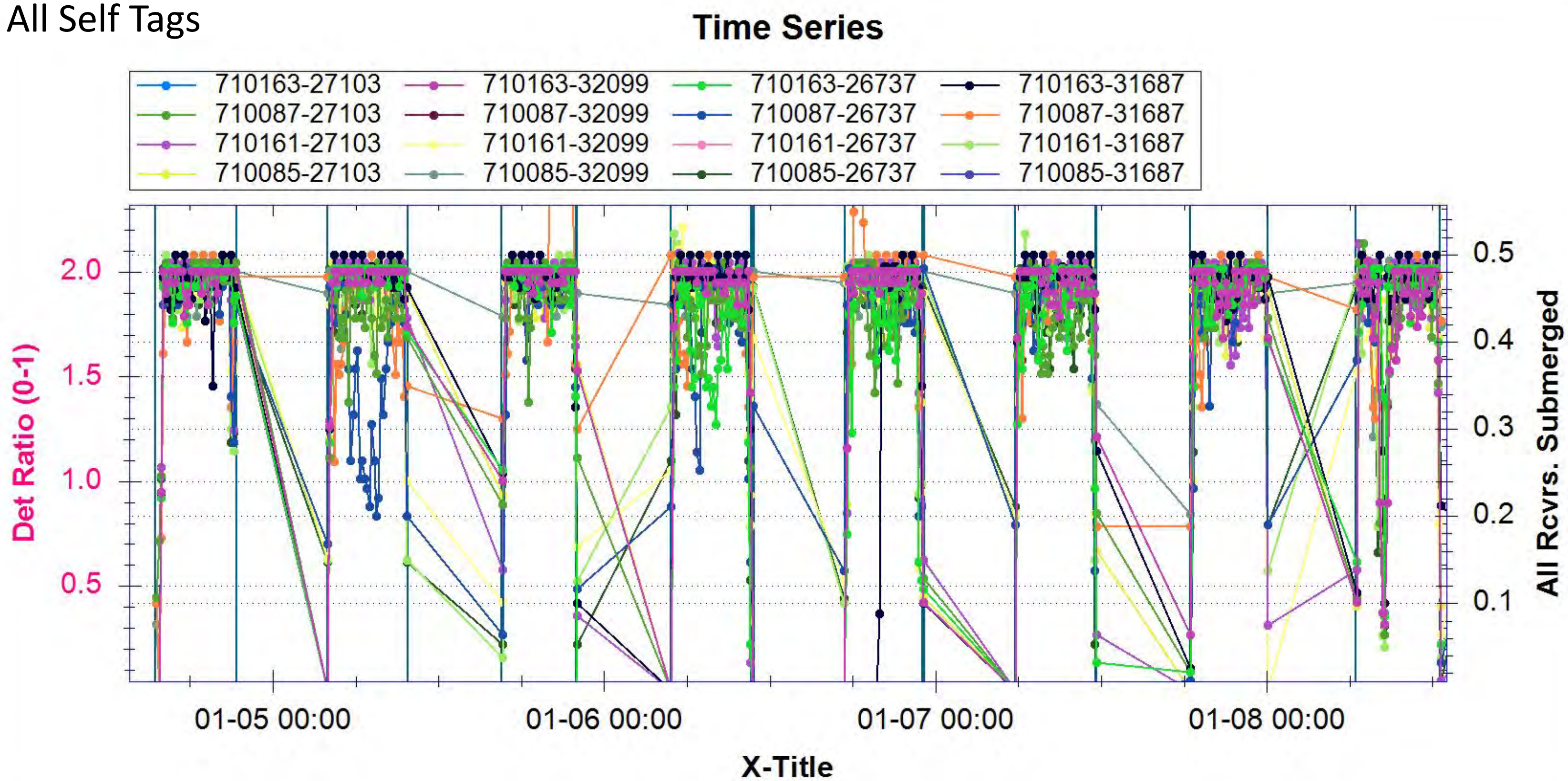
Rcvr. to Rcvr. Detection Performance (average over the trial)

All Self Tags



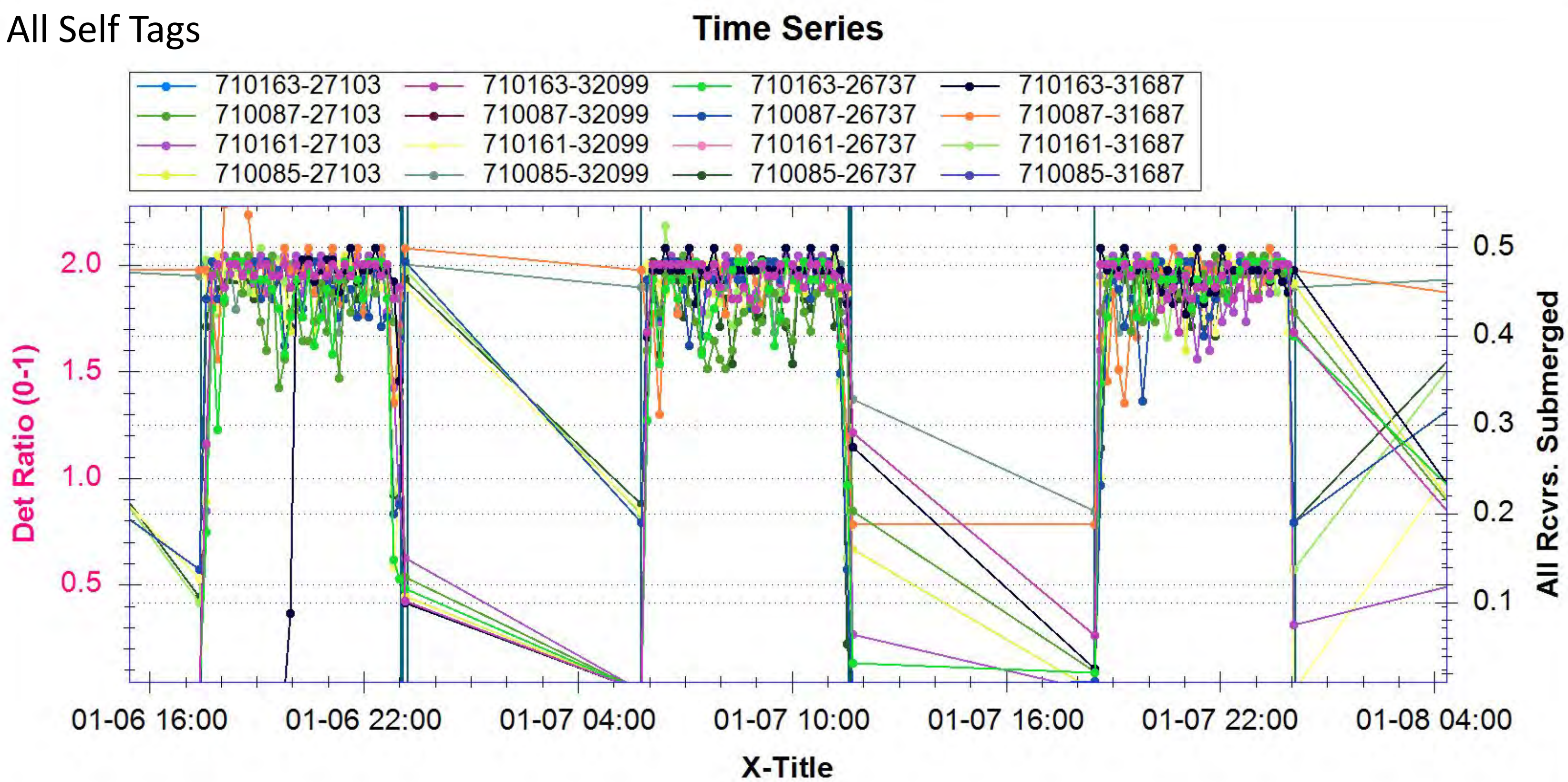
Rcvr. to Rcvr. Detection Performance (average over the trial)

All Self Tags



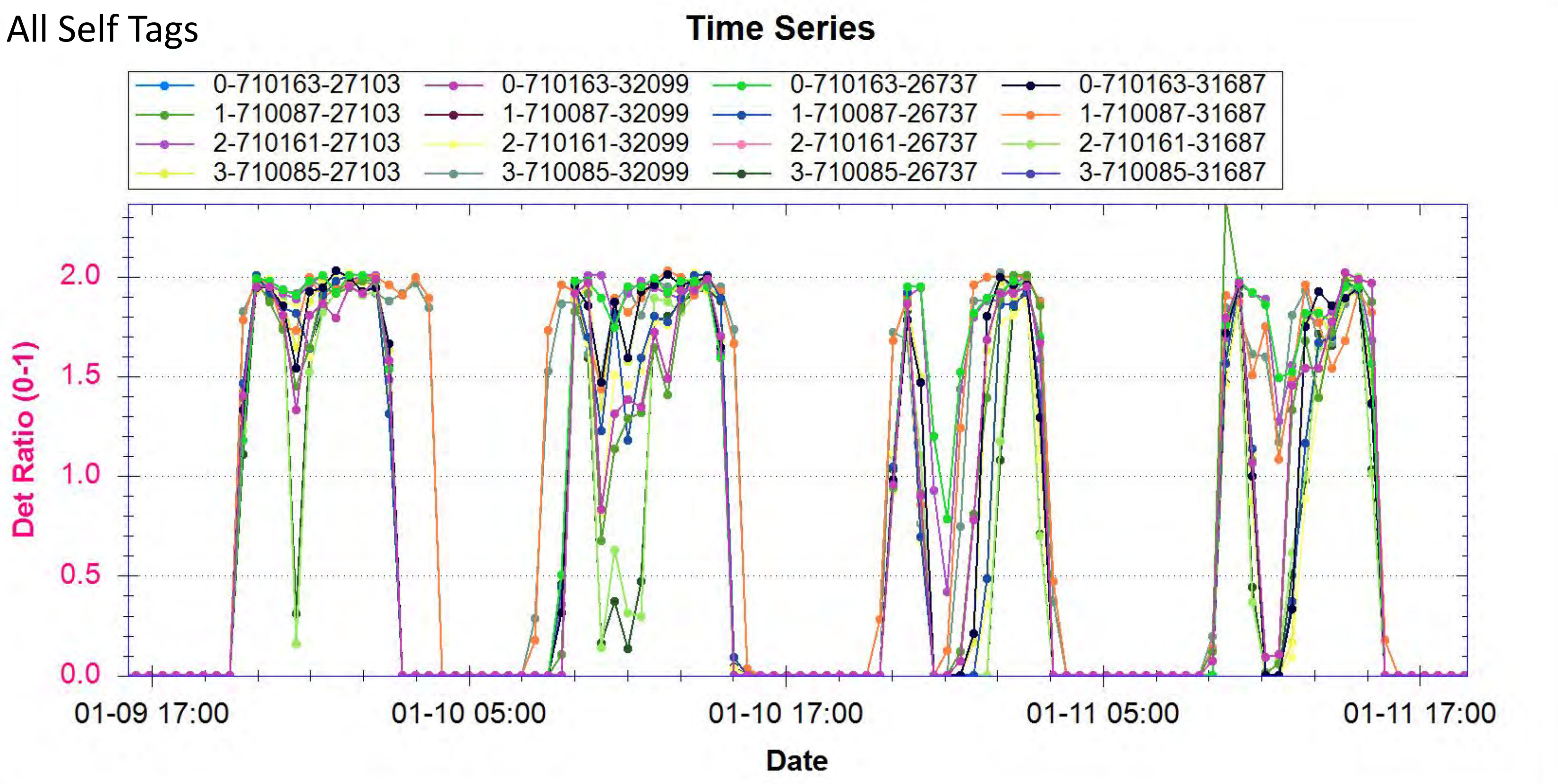
Rcvr. to Rcvr. Detection Performance (average over the trial)

All Self Tags

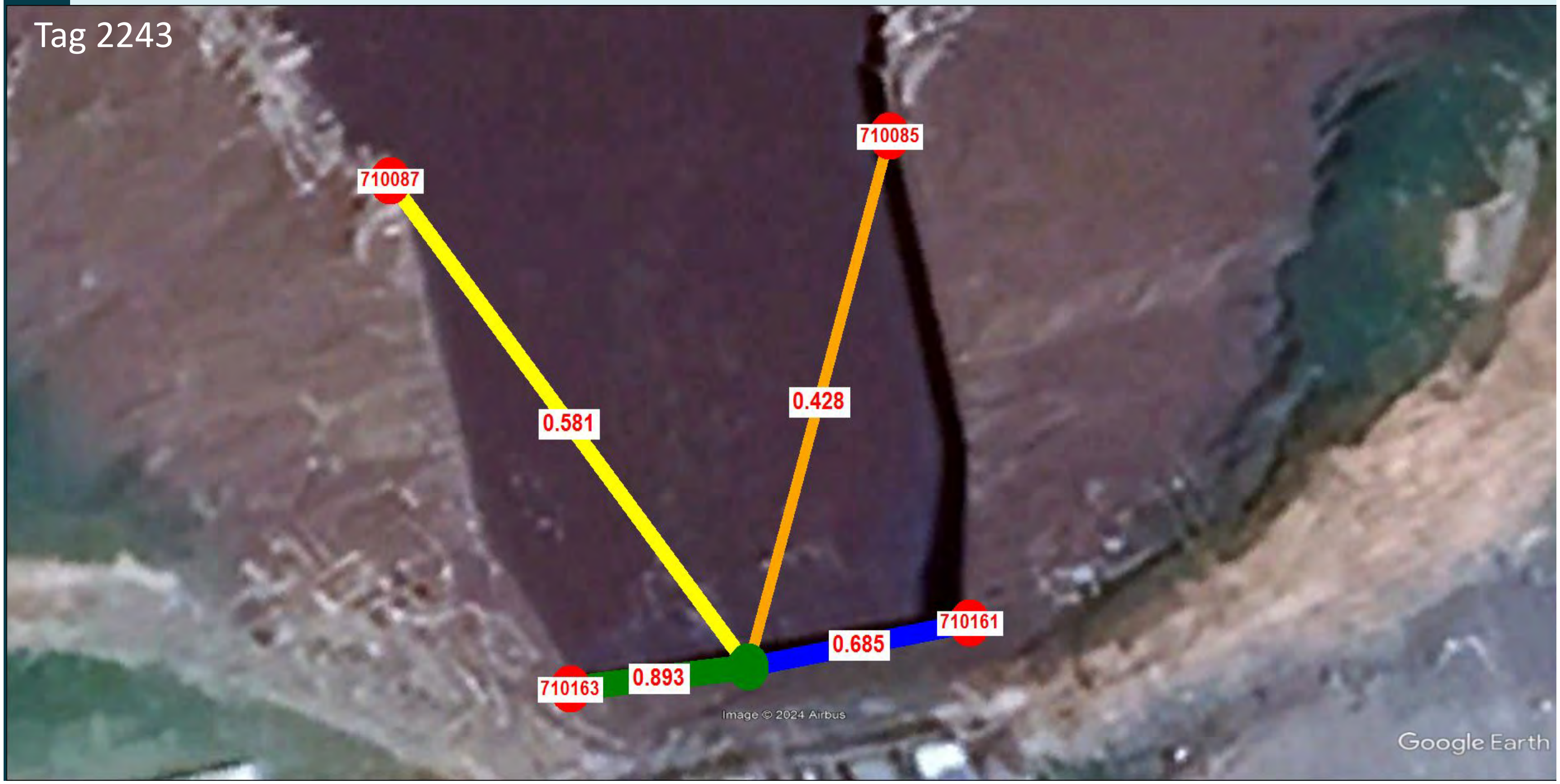


Rcvr. to Rcvr. Detection Performance (average over the trial)

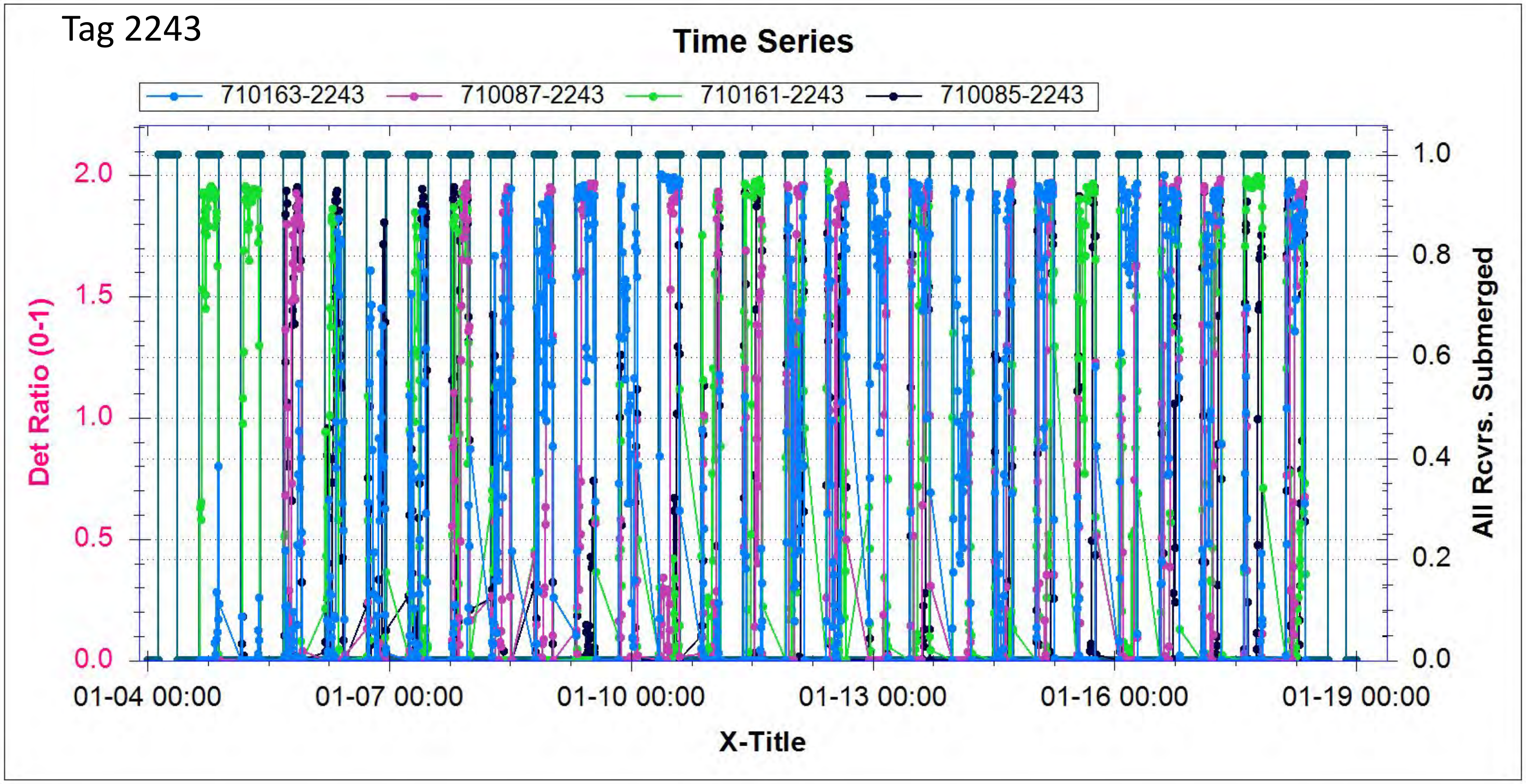
All Self Tags



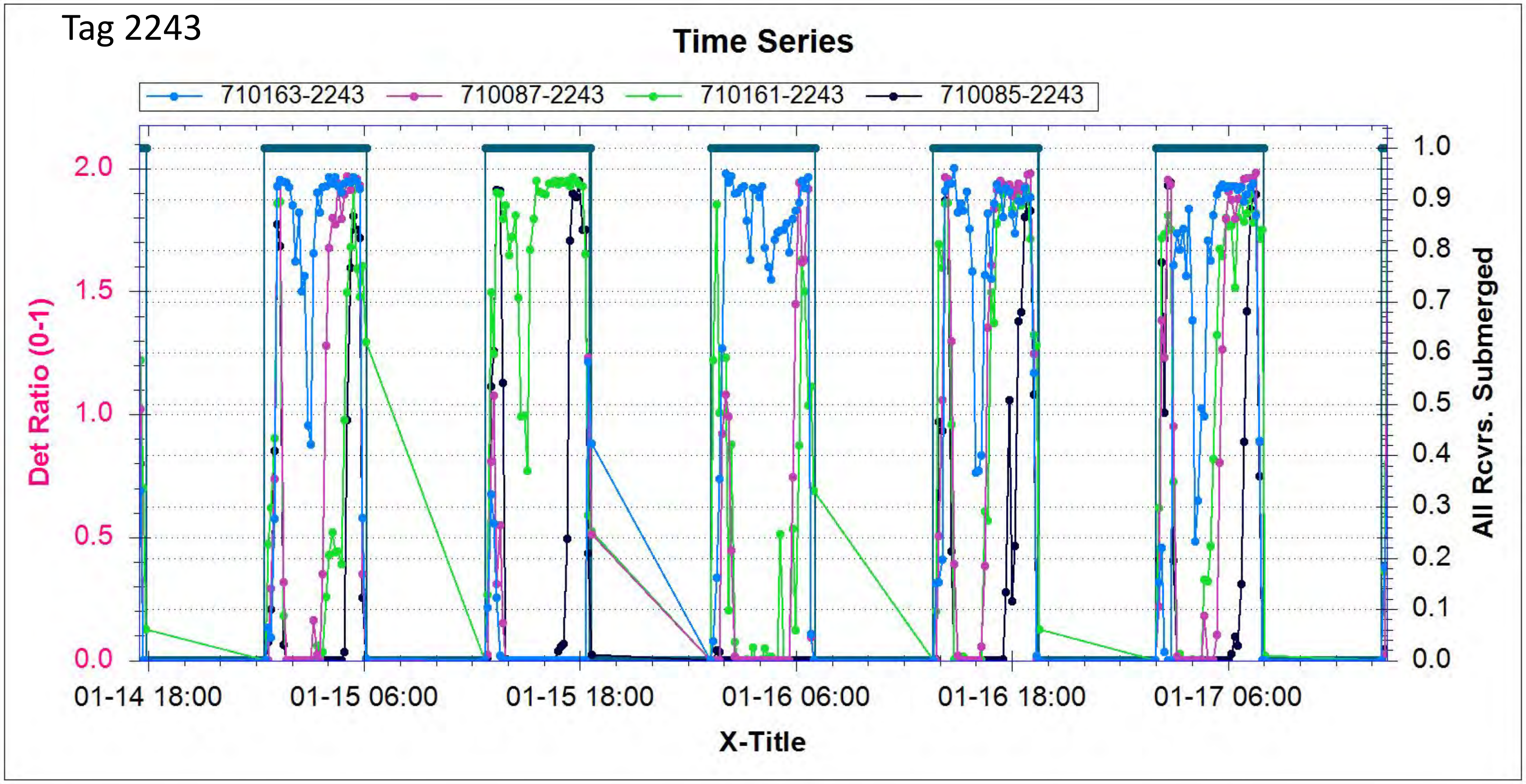
Rcvr. to Rcvr. Detection Performance (average over the trial)



Rcvr. to Rcvr. Detection Performance (average over the trial)

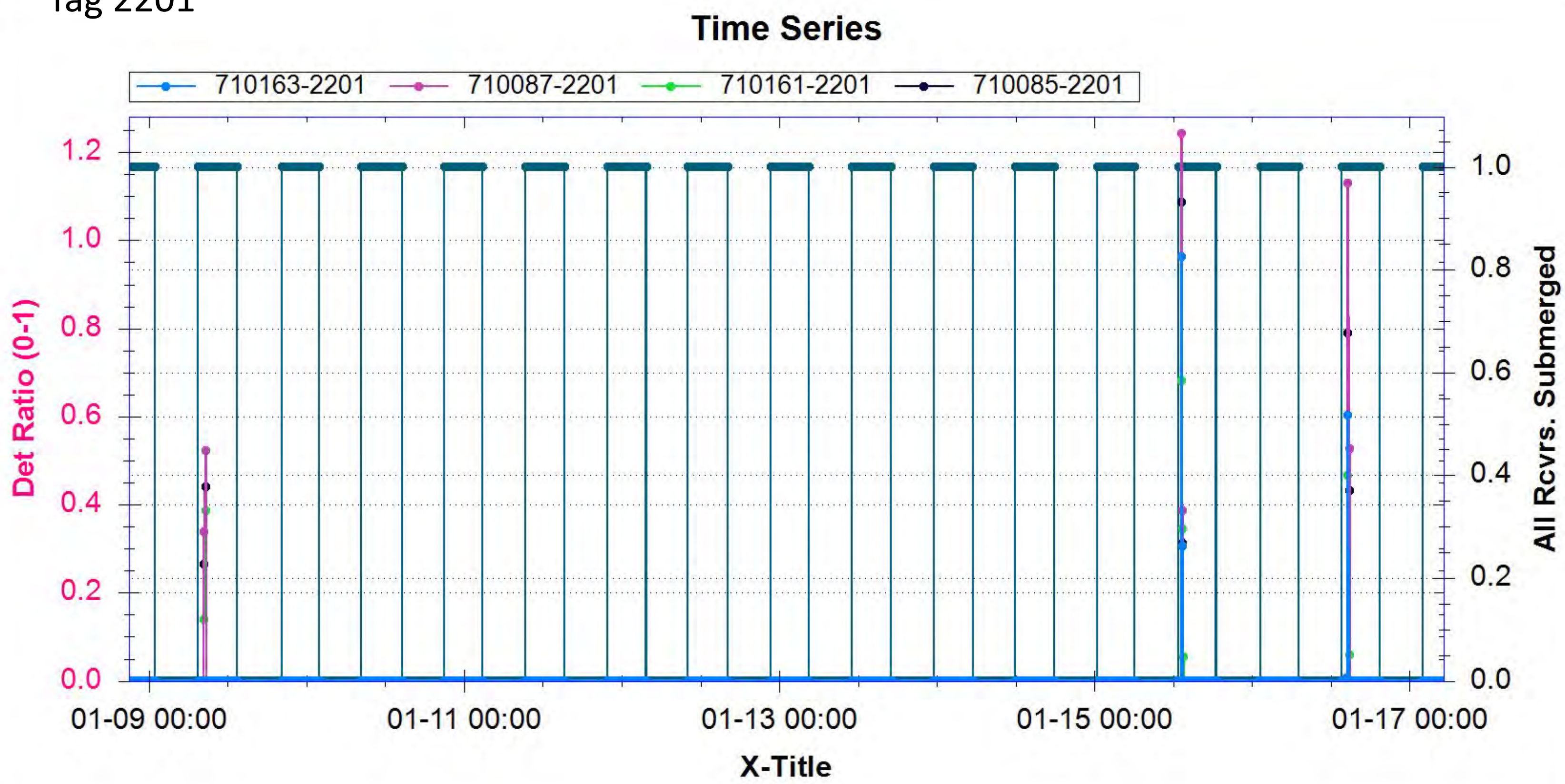


Rcvr. to Rcvr. Detection Performance (average over the trial)



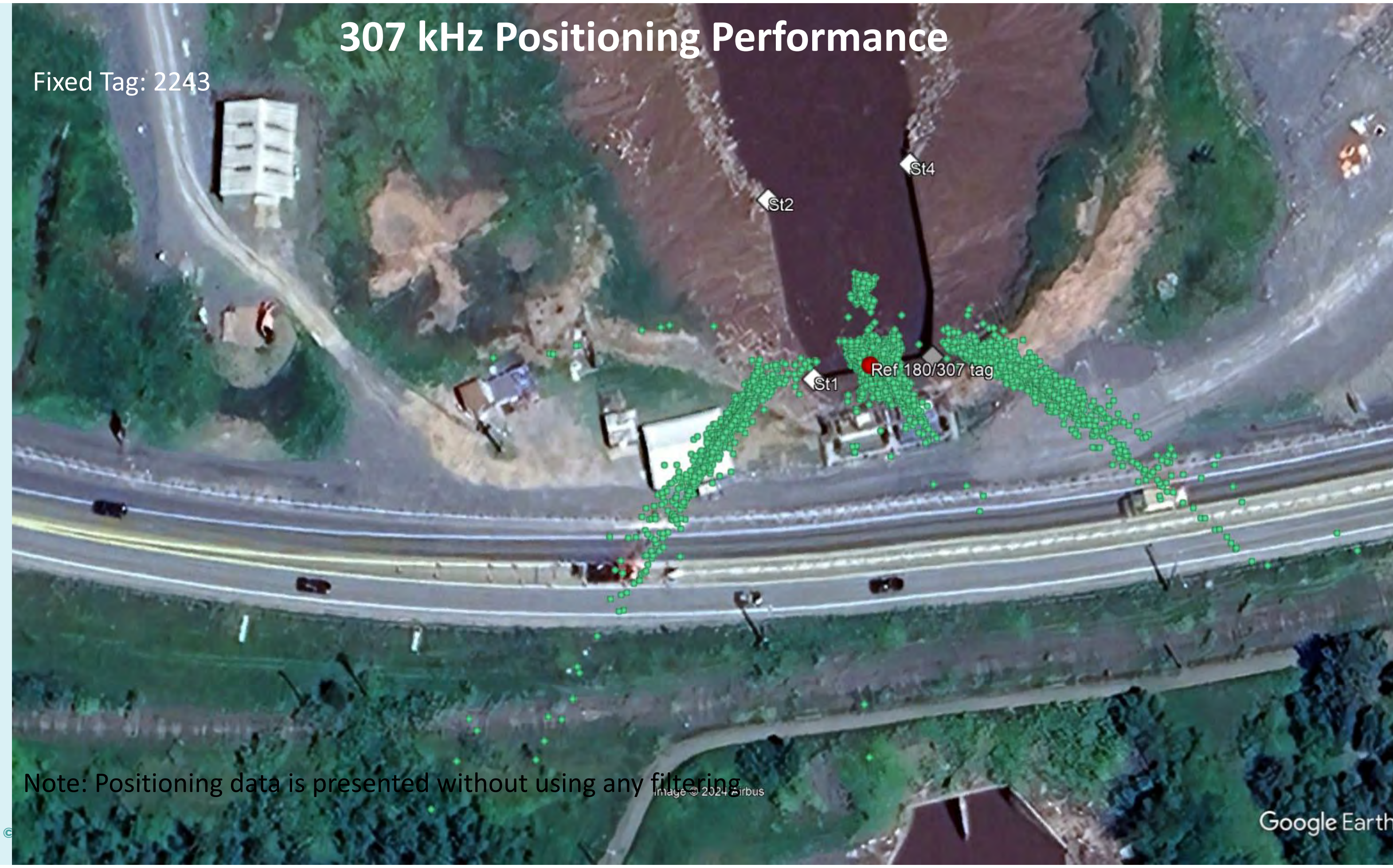
Rcvr. to Rcvr. Detection Performance (average over the trial)

Tag 2201

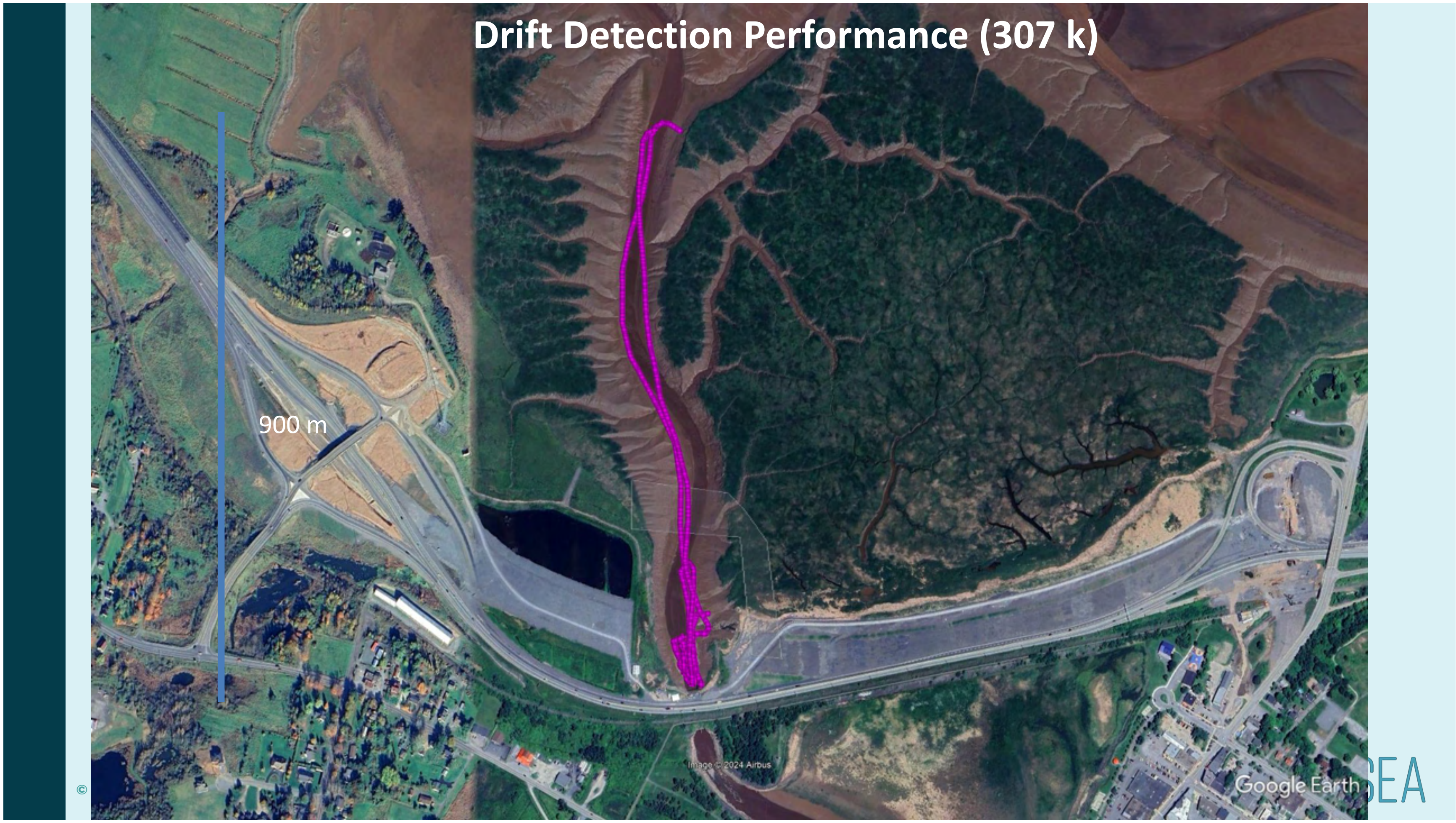


307 kHz Positioning Performance

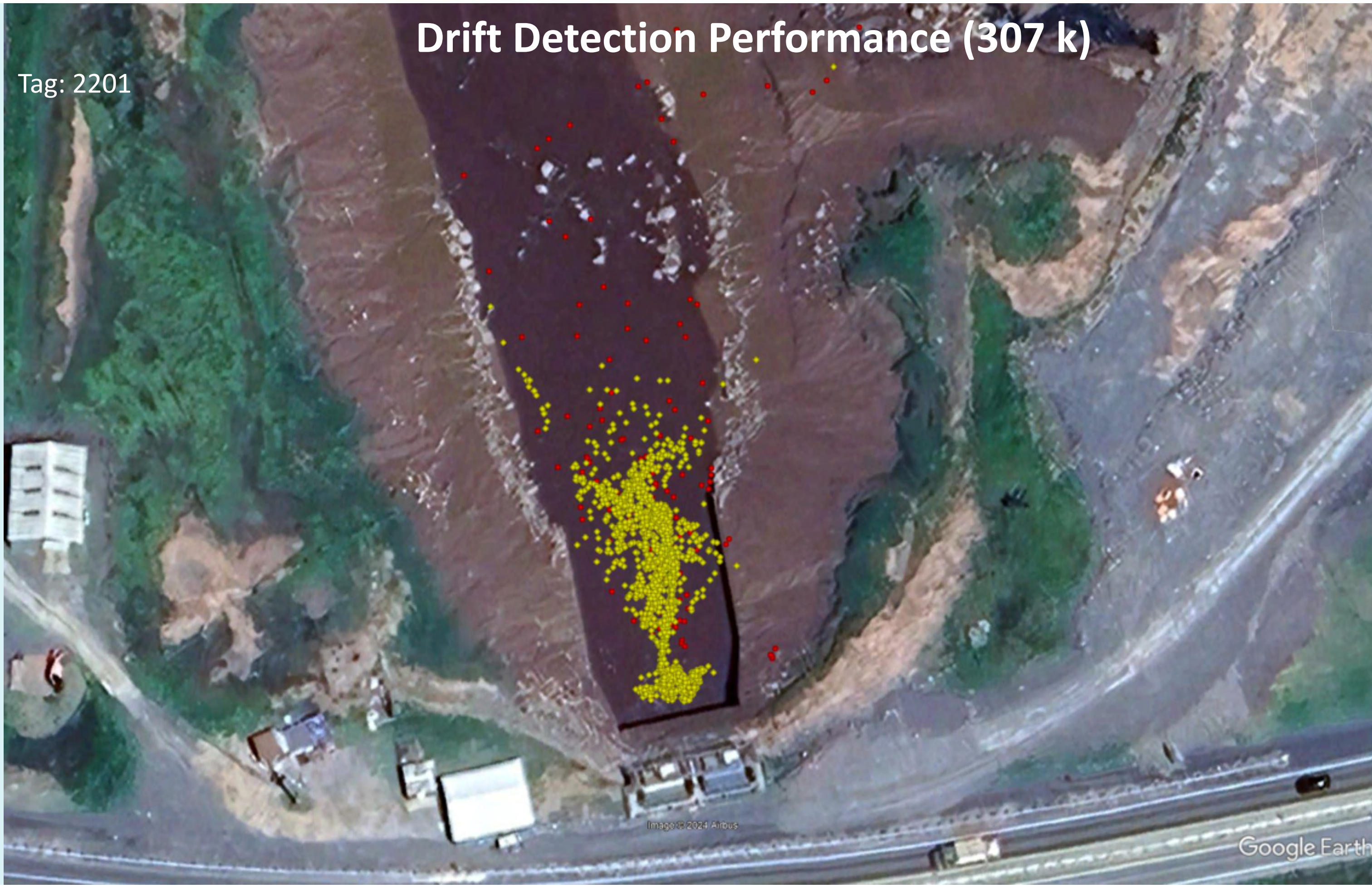
Fixed Tag: 2243



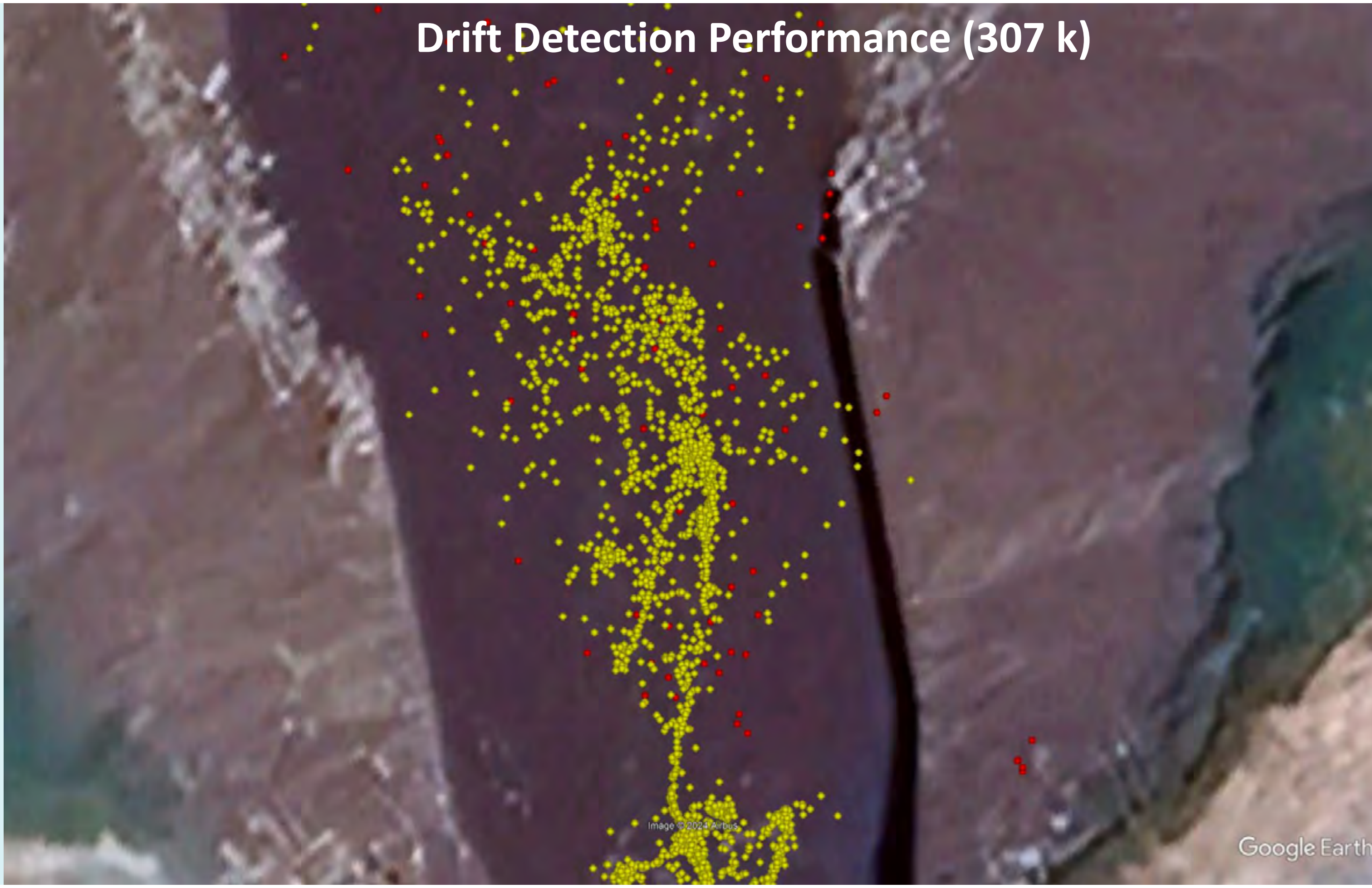
Note: Positioning data is presented without using any filtering


Drift Detection Performance (307 k)
900 m
Image © 2024 Airbus
Google Earth
SEA

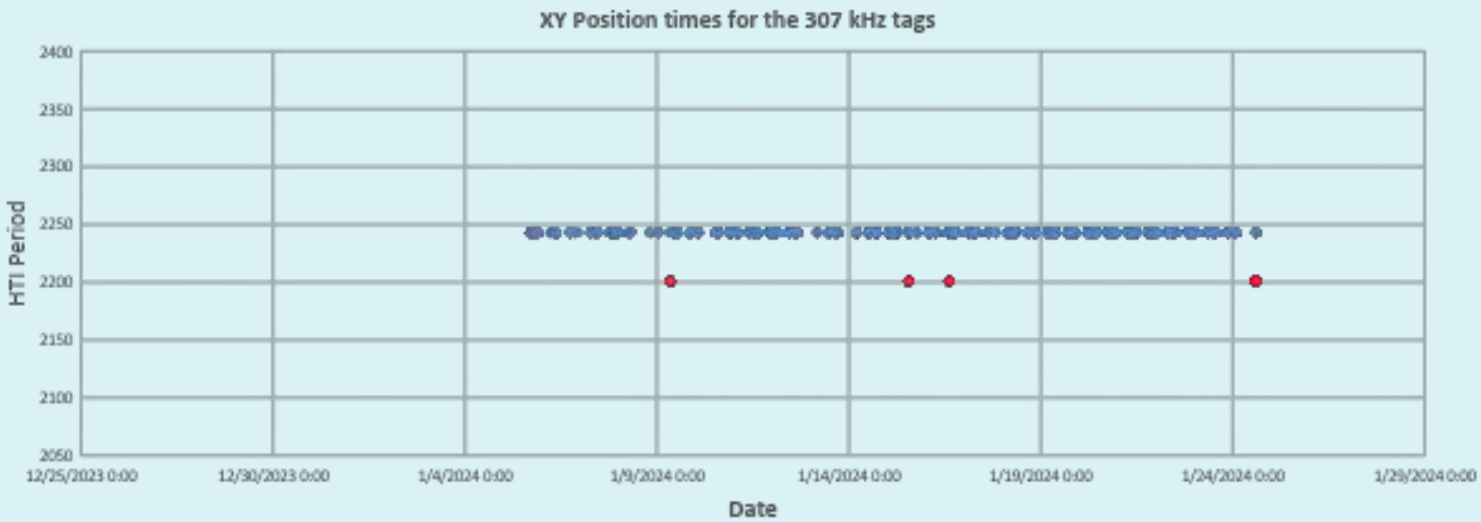
Drift Detection Performance (307 k)



Drift Detection Performance (307 k)

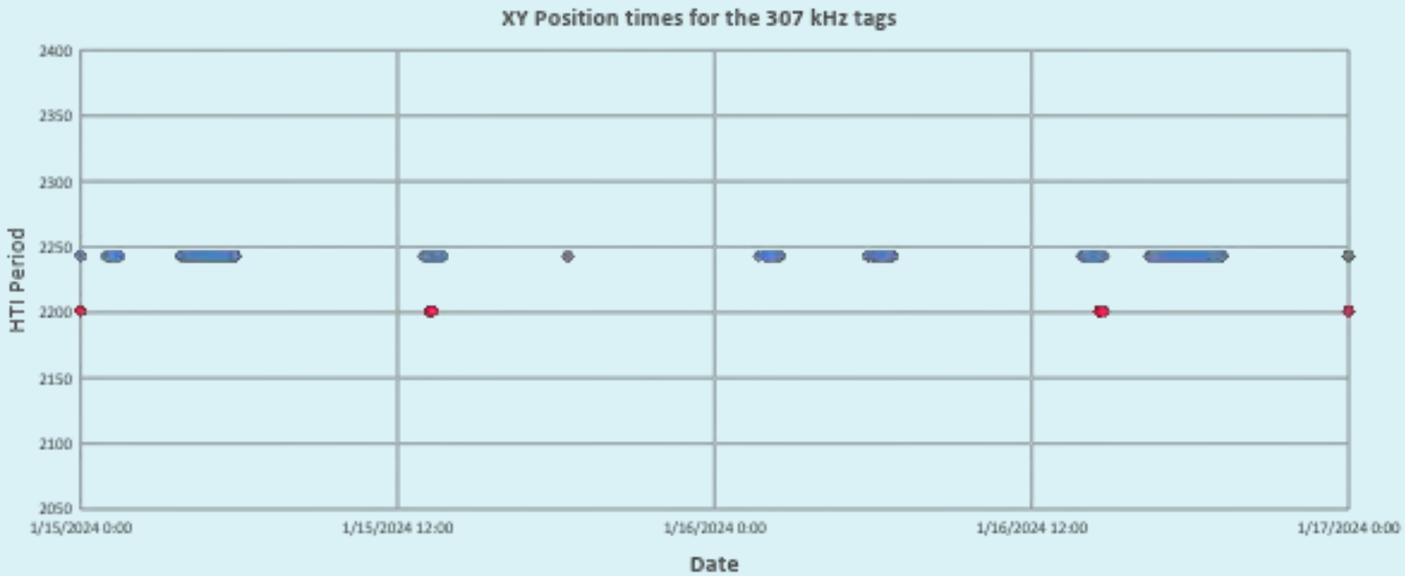


Time of XY Position Data (307 kHz)

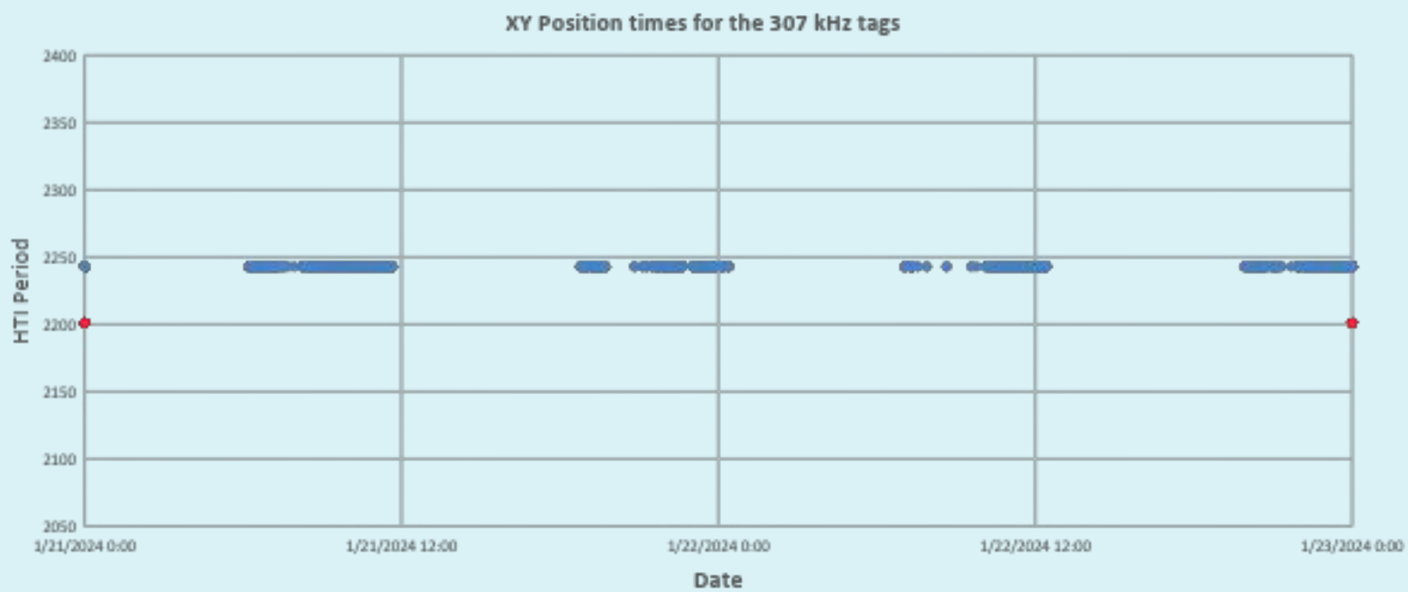


INNOVASEA

Time of XY Position Data (307 kHz) (Zoomed in)

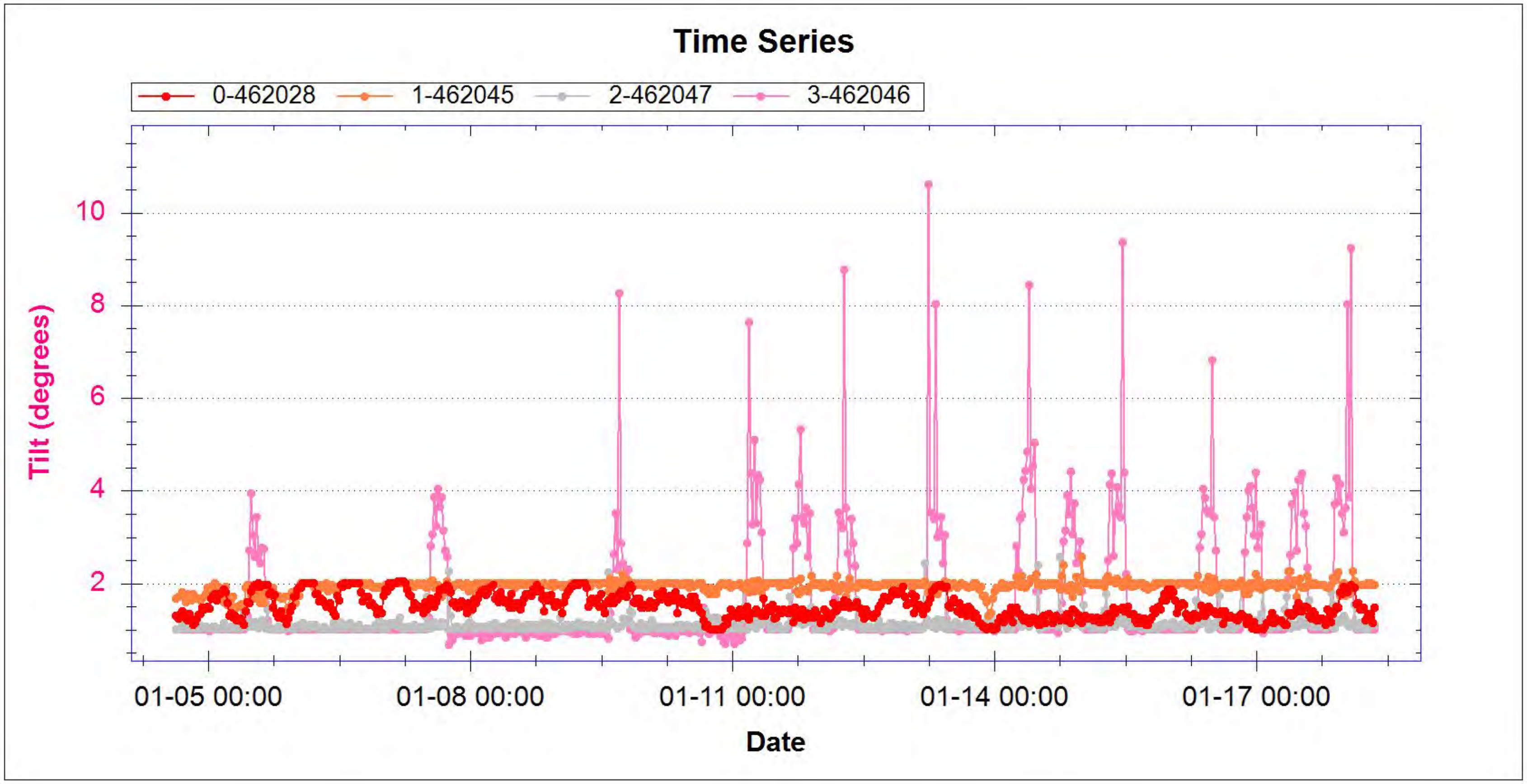


Time of XY Position Data (307 kHz) (Zoomed in)



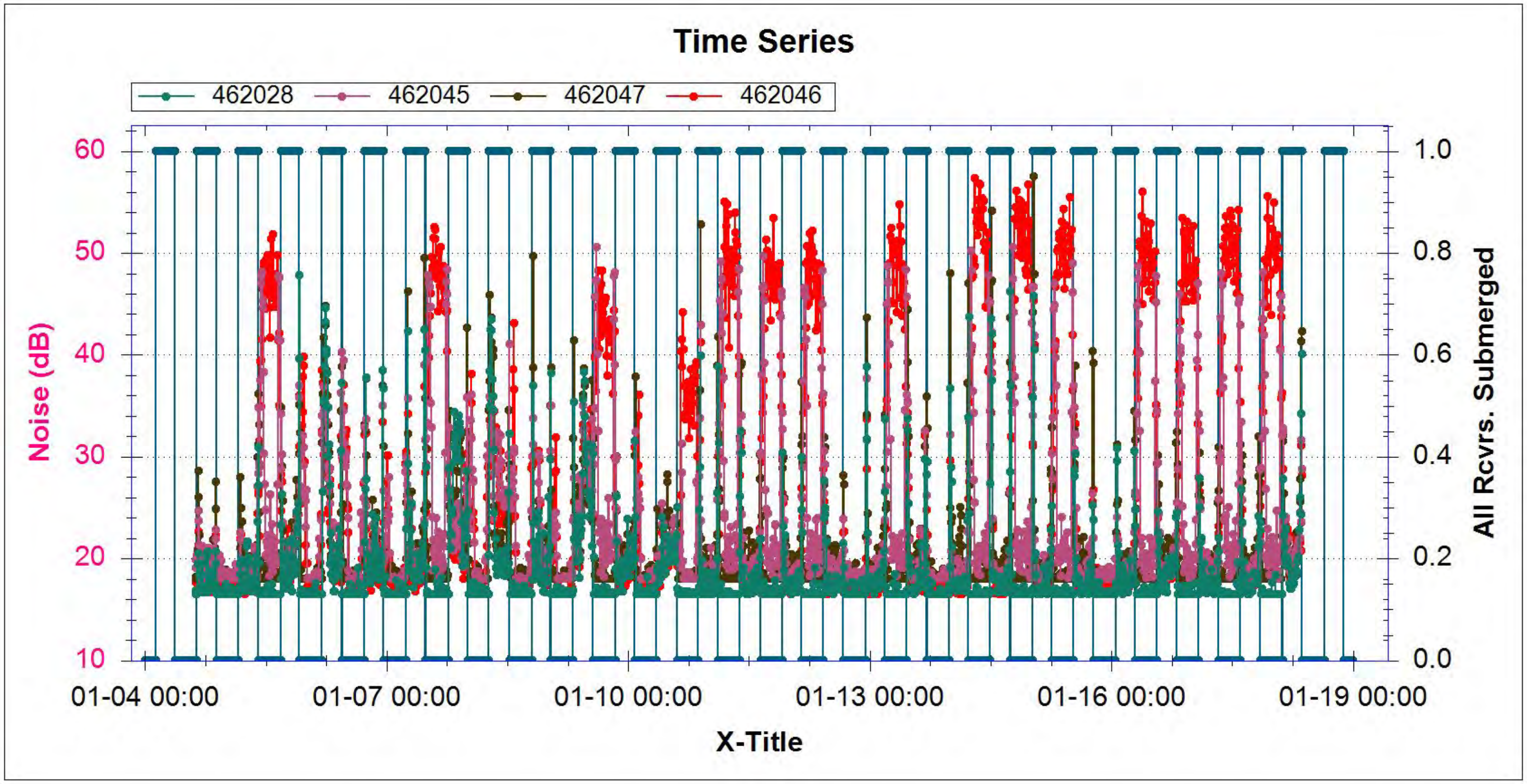
180 kHz – HR2s

Tilt – 180 kHz

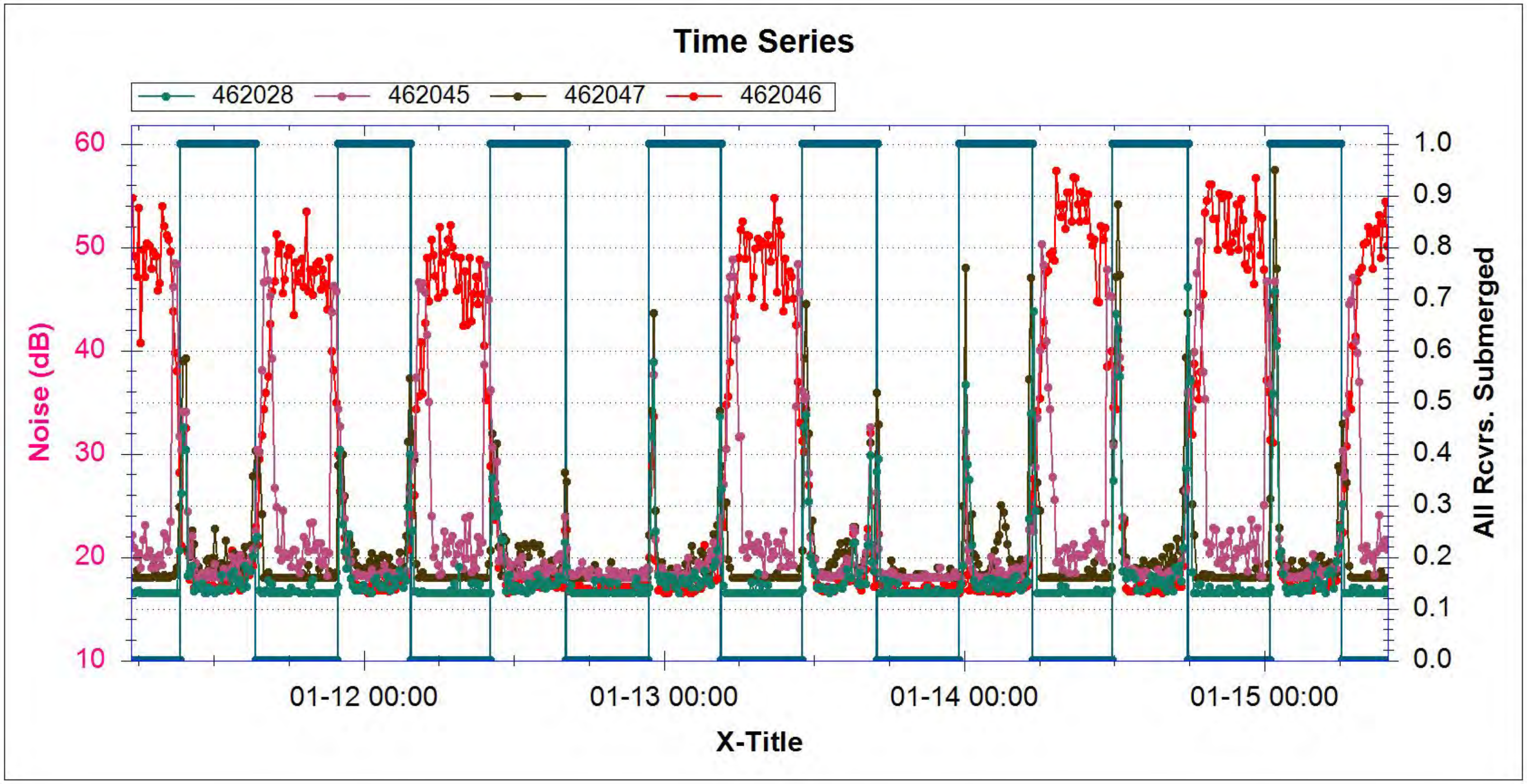


Time Series
0-462028
1-462045
2-462047
3-462046
Tilt (degrees)
10
8
6
4
2
01-05 00:00
01-08 00:00
01-11 00:00
01-14 00:00
01-17 00:00
Date

Noise – 180 kHz

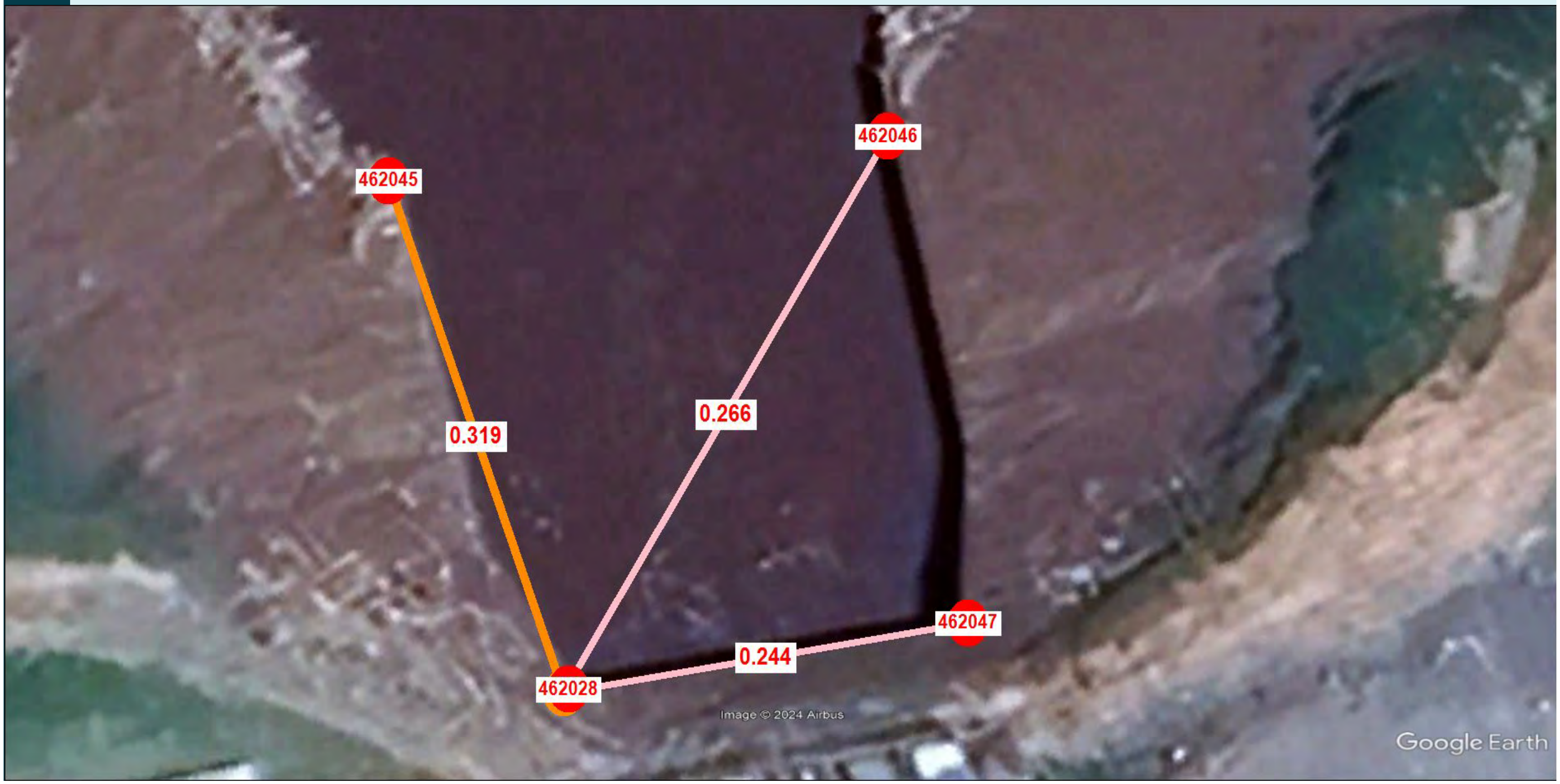


Noise – 180 kHz



Rcvr. to Rcvr. Detection Performance (average over the trial)

180 kHz



180 kHz

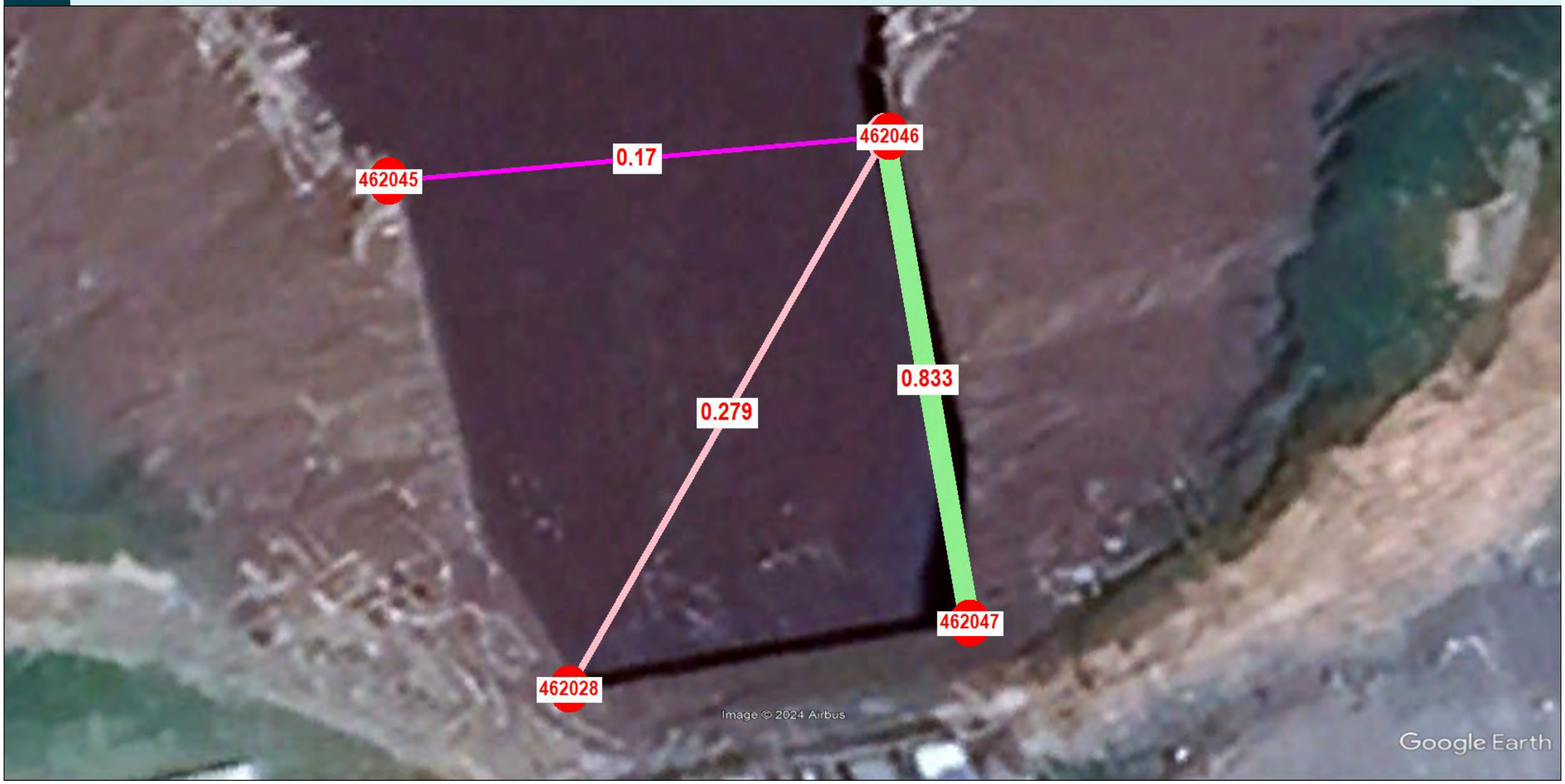
Rcvr. to Rcvr. Detection Performance (average over the trial)

180 kHz

Rcvr. to Rcvr. Detection Performance (average over the trial)

180 kHz

Rcvr. to Rcvr. Detection Performance (average over the trial)



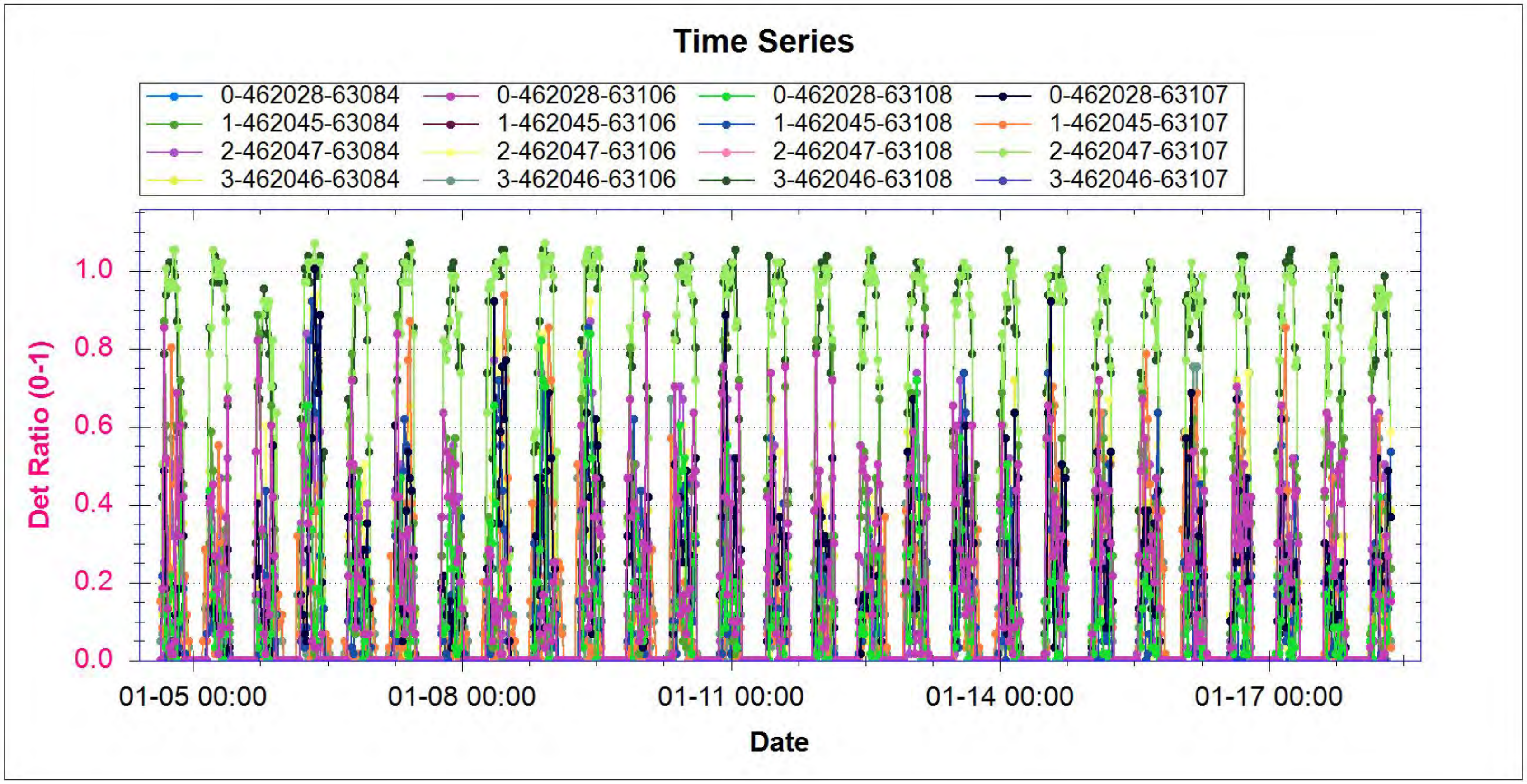
Rcvr. Detection Performance of the Fixed Ref Tag (average over the trial)

180 kHz

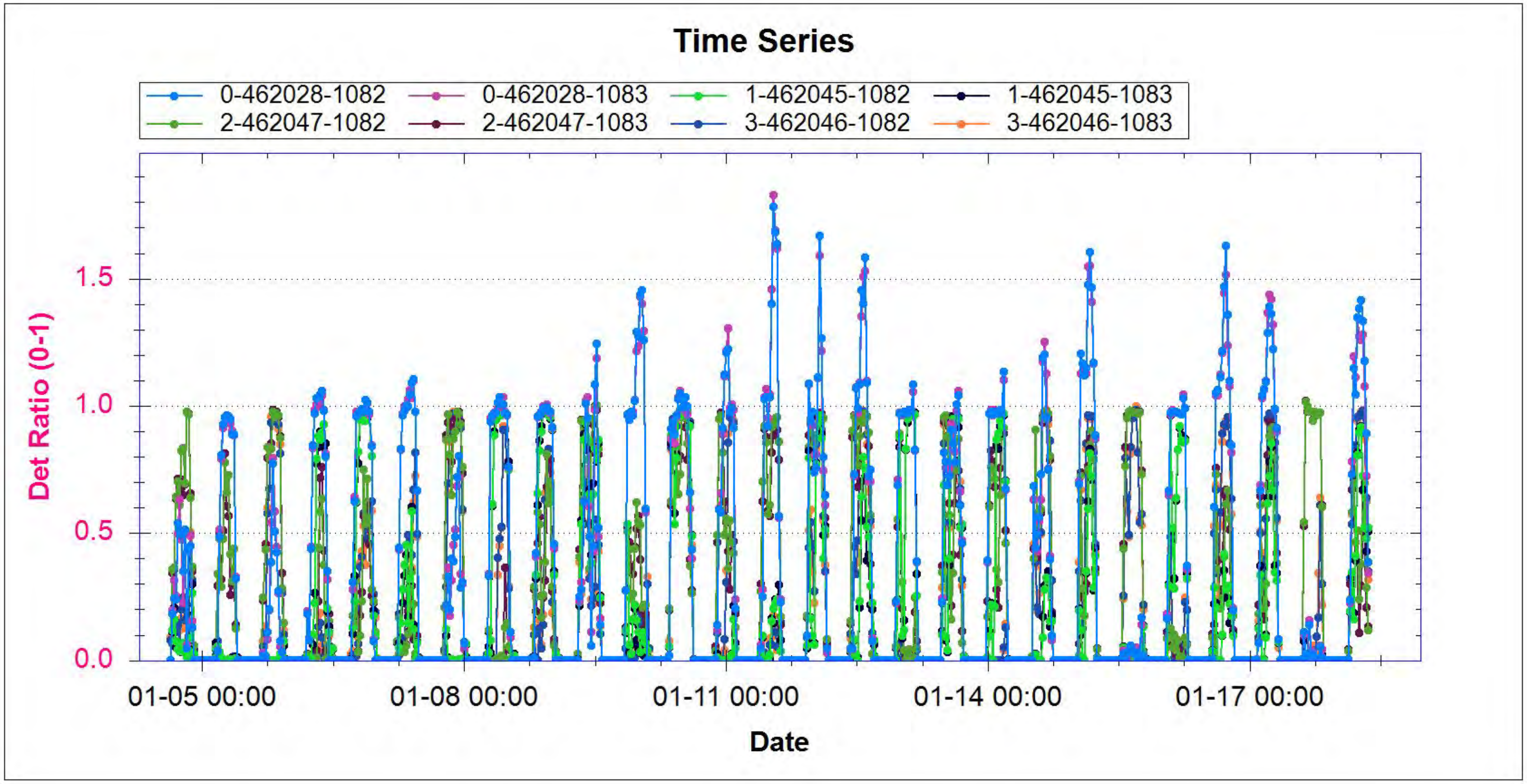
Rcvr. Detection Performance of the Fixed Ref Tag (average over the trial)

180 kHz

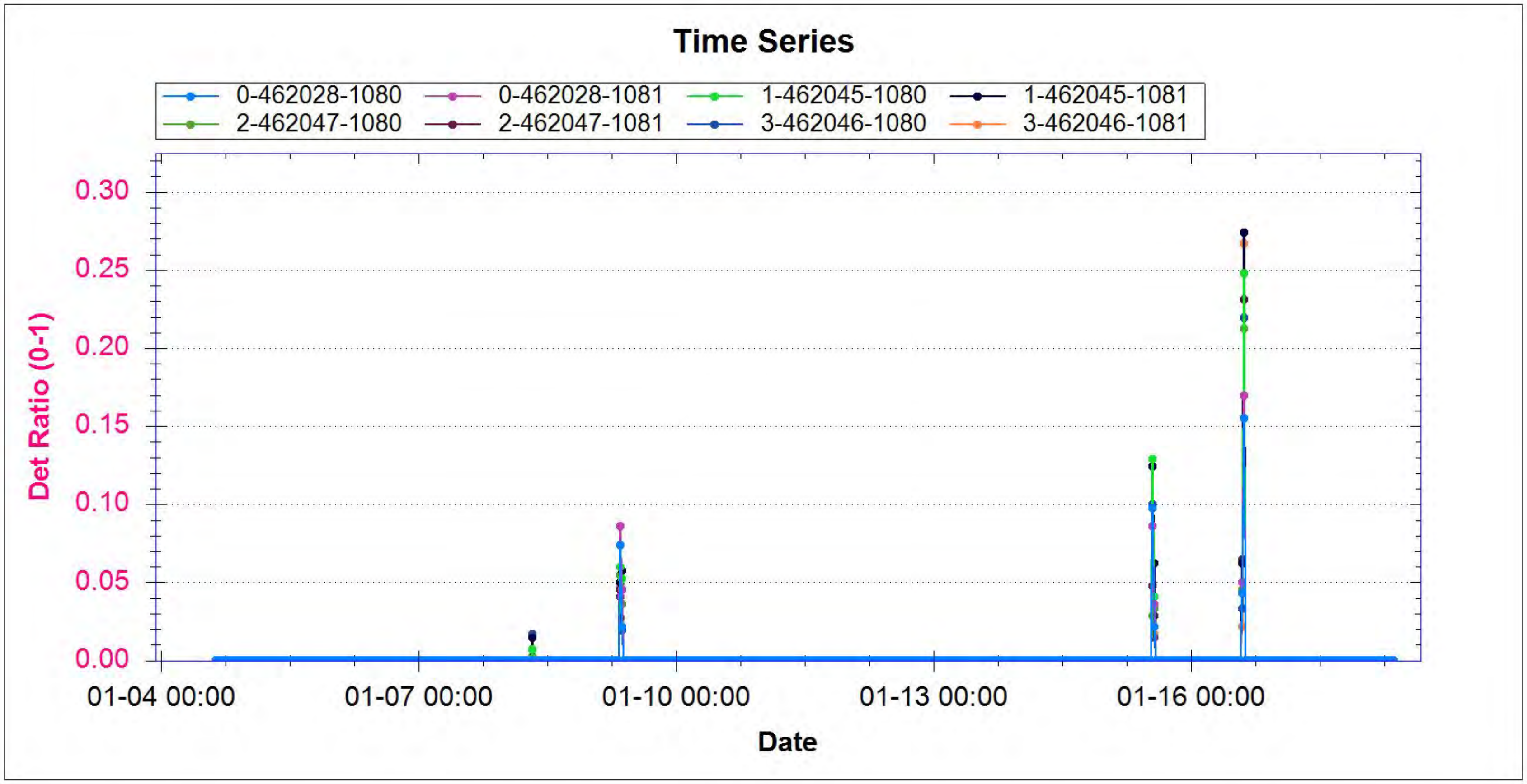
Rcvr. to Rcvr. Detection Performance (10 min Bins)



Rcvr. Detection Performance of the Fixed Ref Tag (10 min bins)

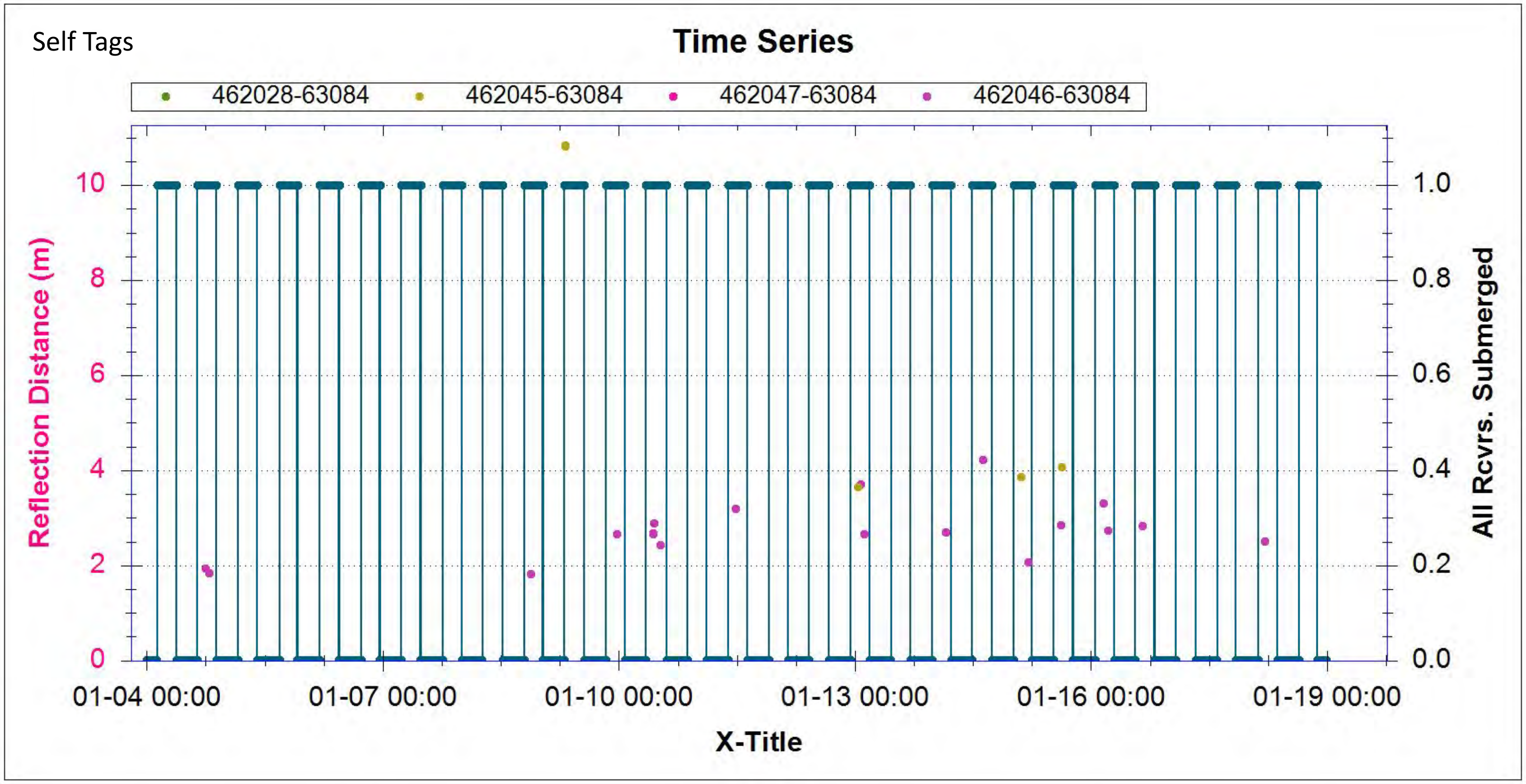


Rcvr. Detection Performance of the Fixed Ref Tag (average over the trial)



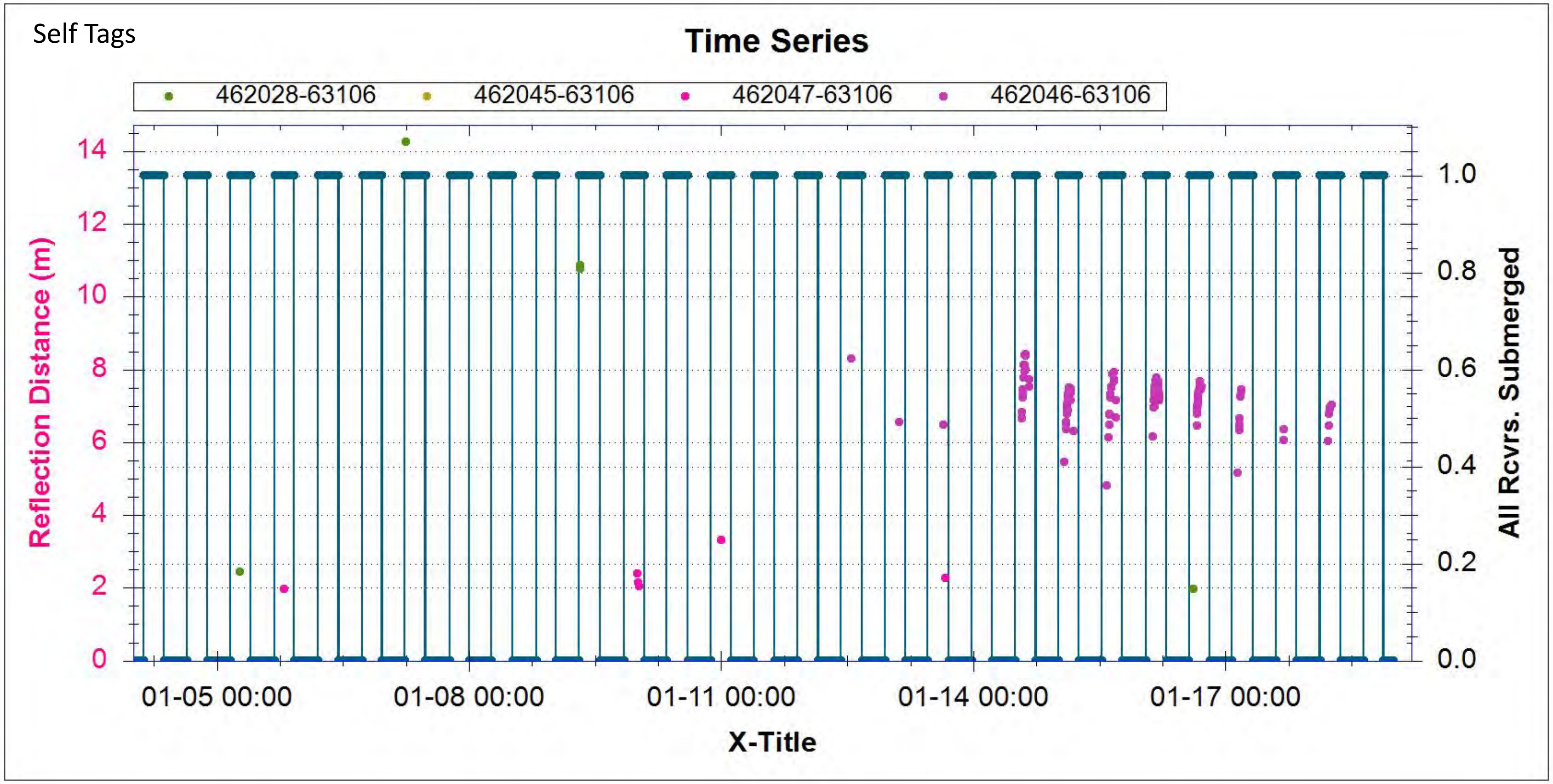
Rcvr. Detection Performance (Reflections)

180 kHz



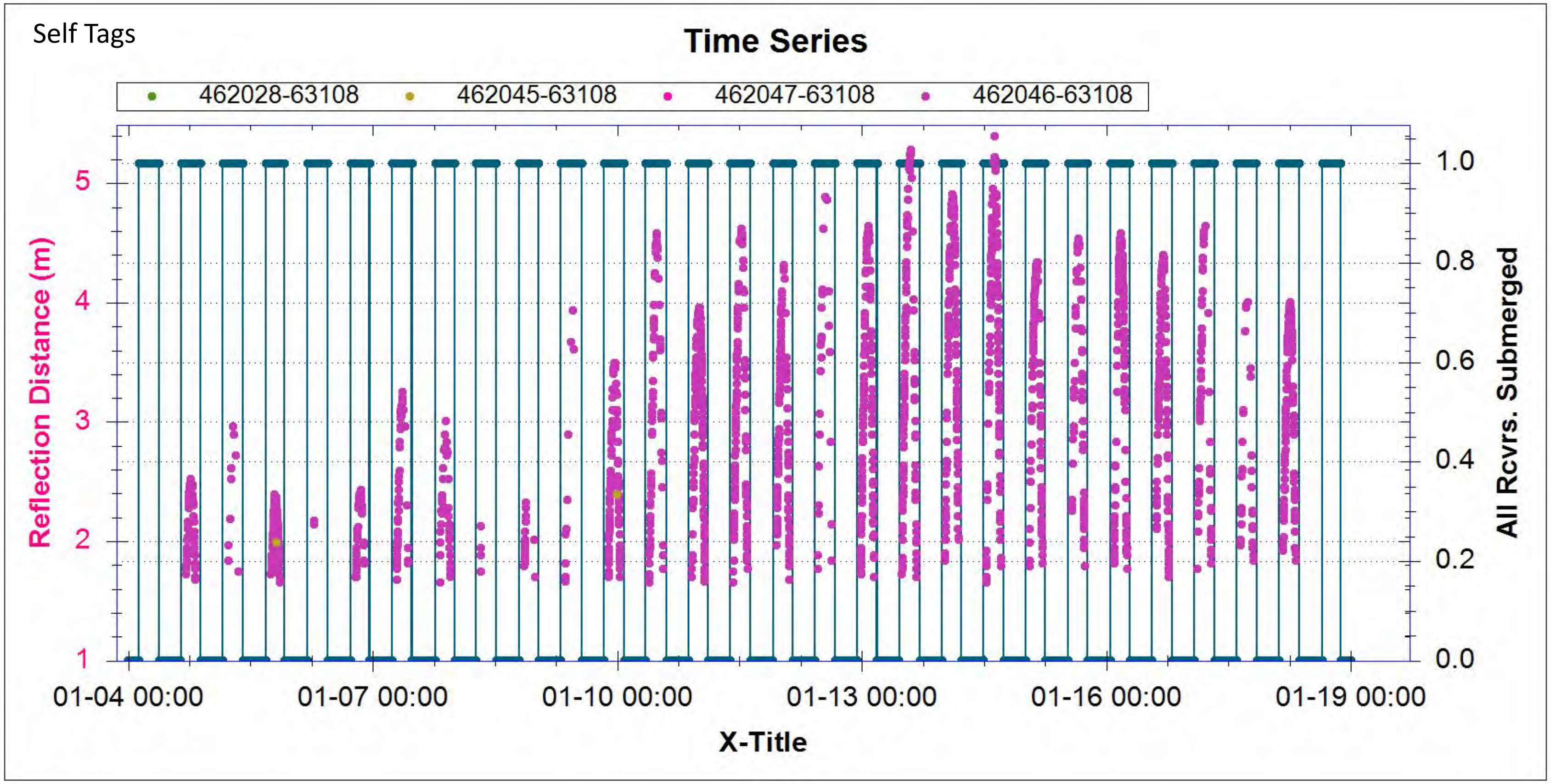
Rcvr. Detection Performance (Reflections)

180 kHz



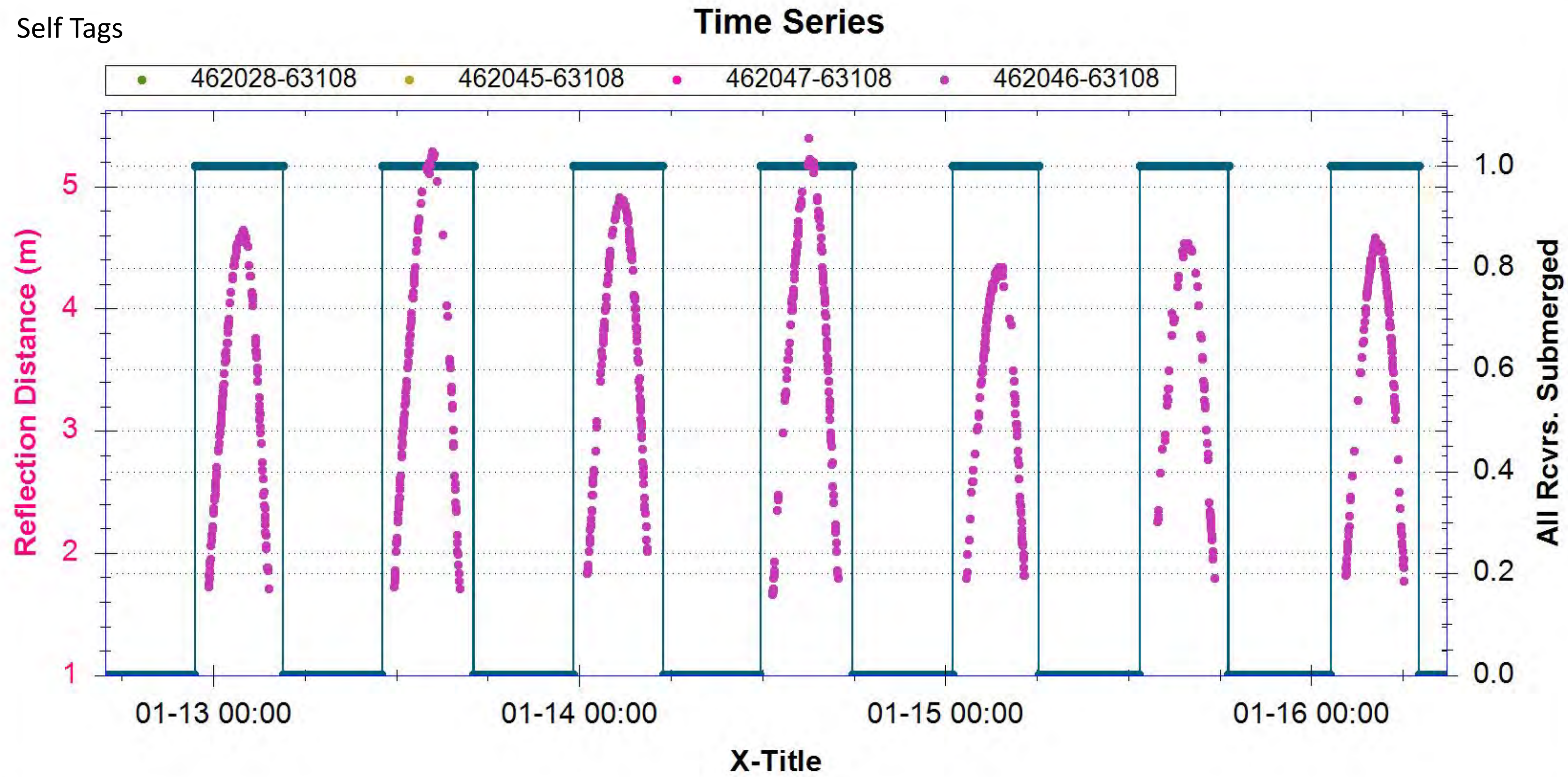
Rcvr. Detection Performance (Reflections)

180 kHz



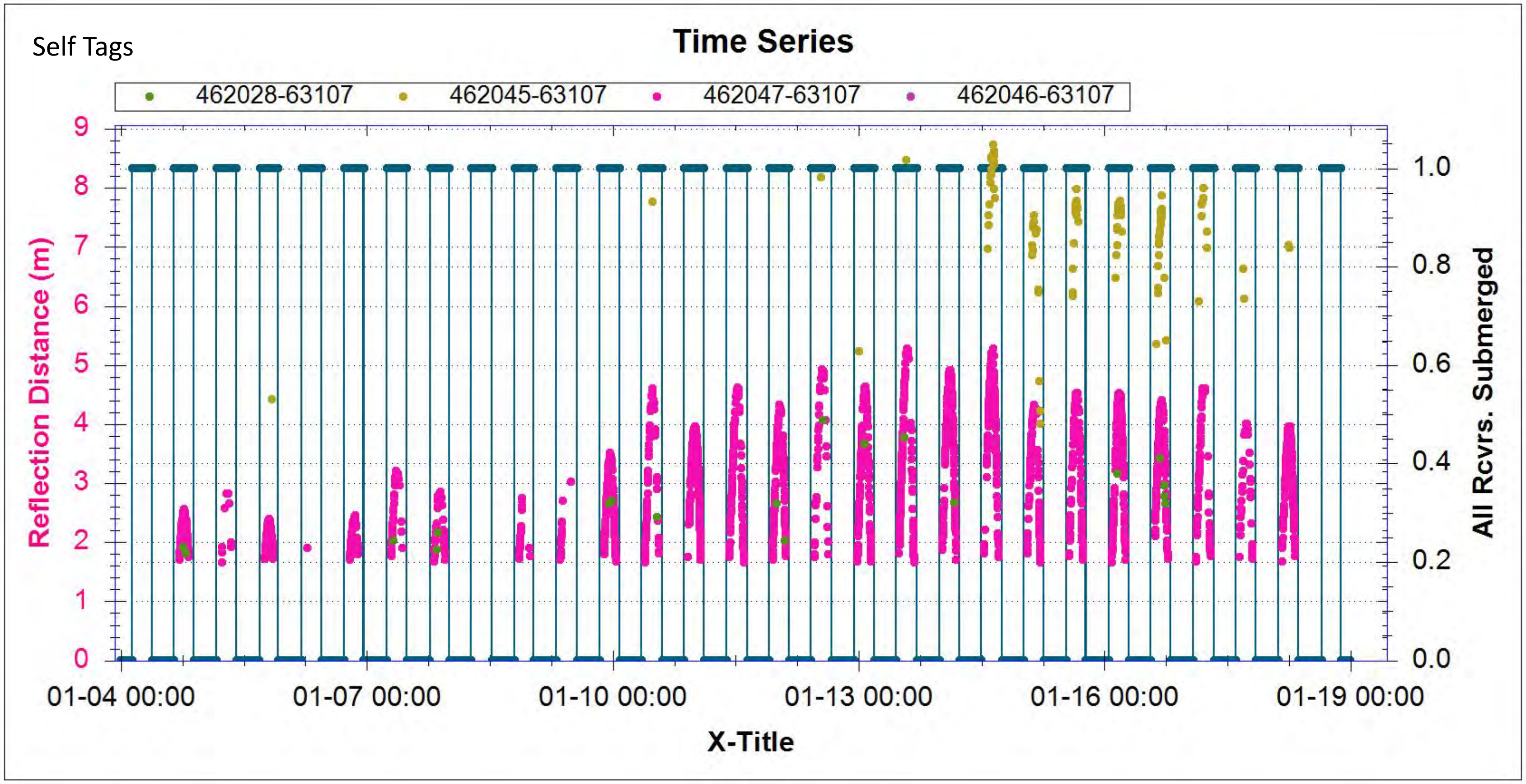
Rcvr. Detection Performance (Reflections)

Self Tags



Rcvr. Detection Performance (Reflections)

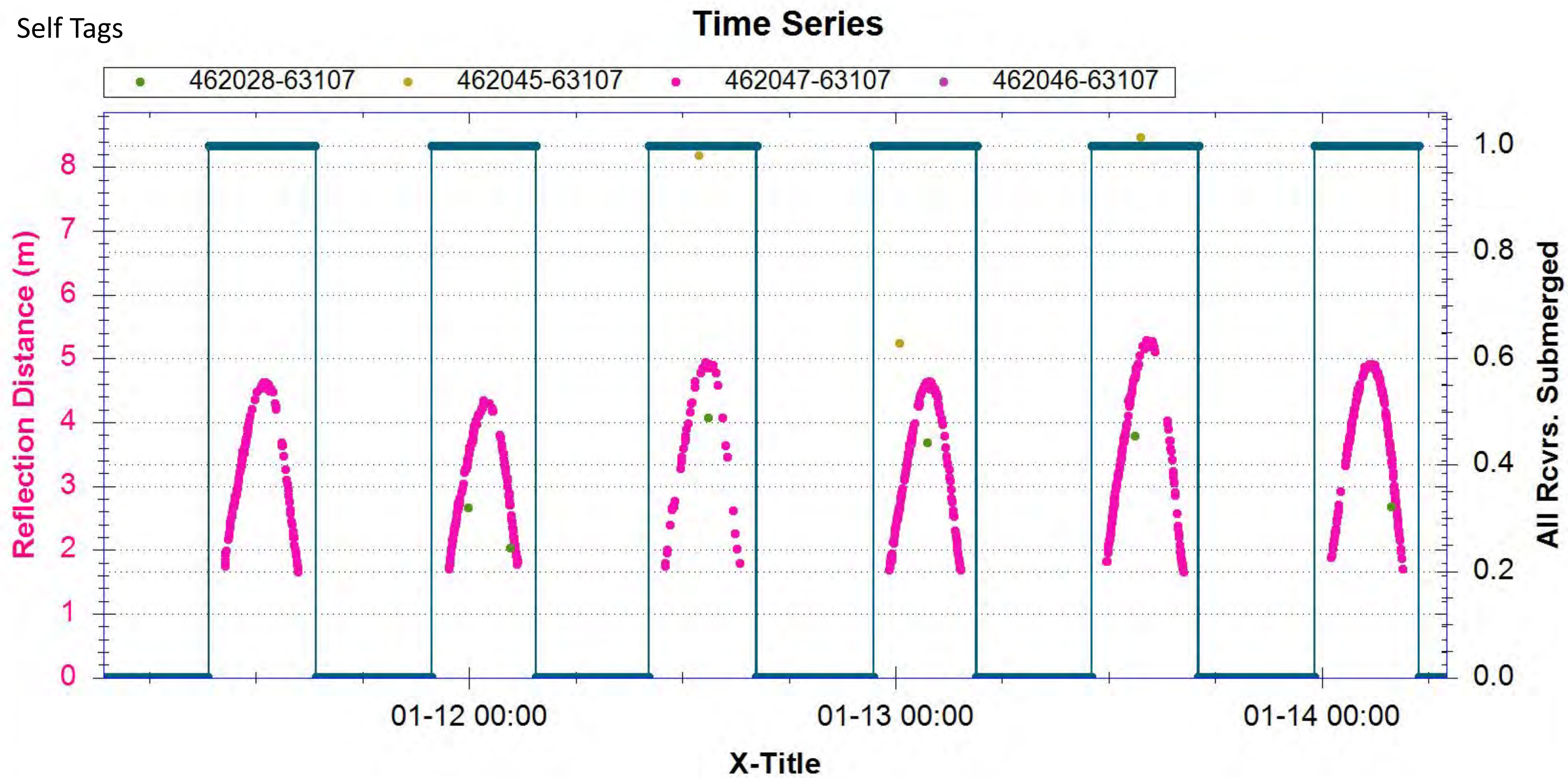
180 kHz



Rcvr. Detection Performance (Reflections)

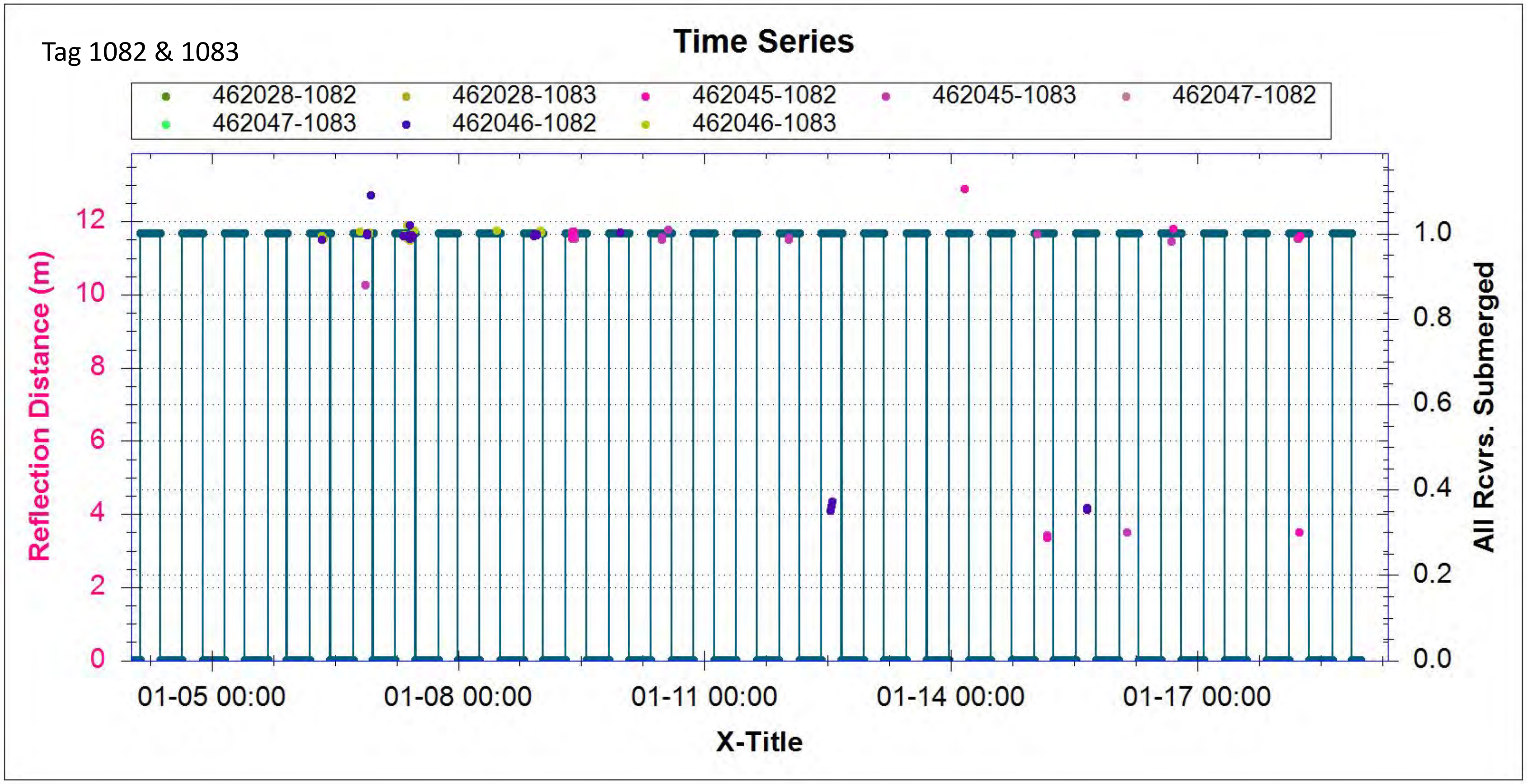
180 kHz

Self Tags



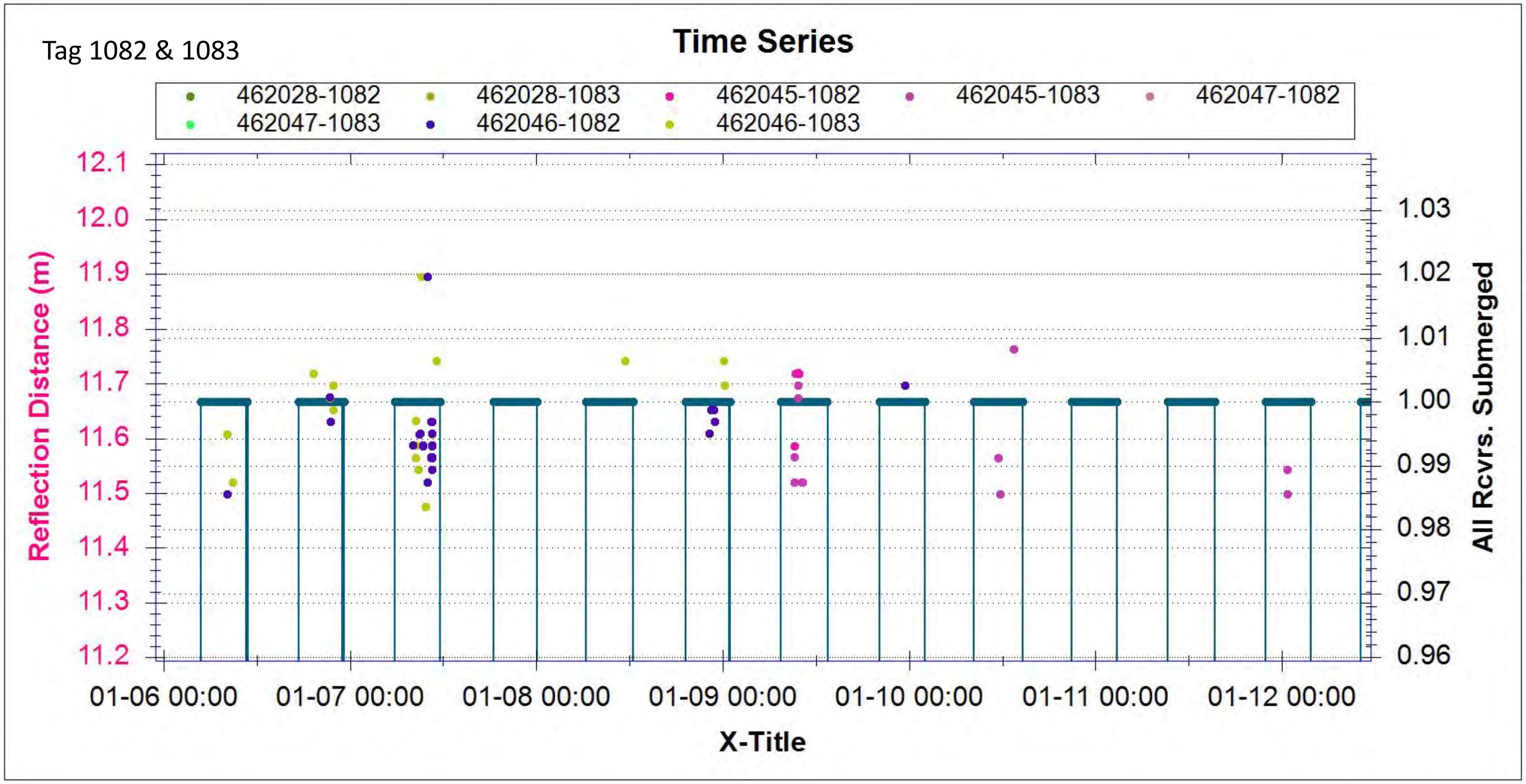
Rcvr. Detection Performance (Reflections)

180 kHz



180 kHz

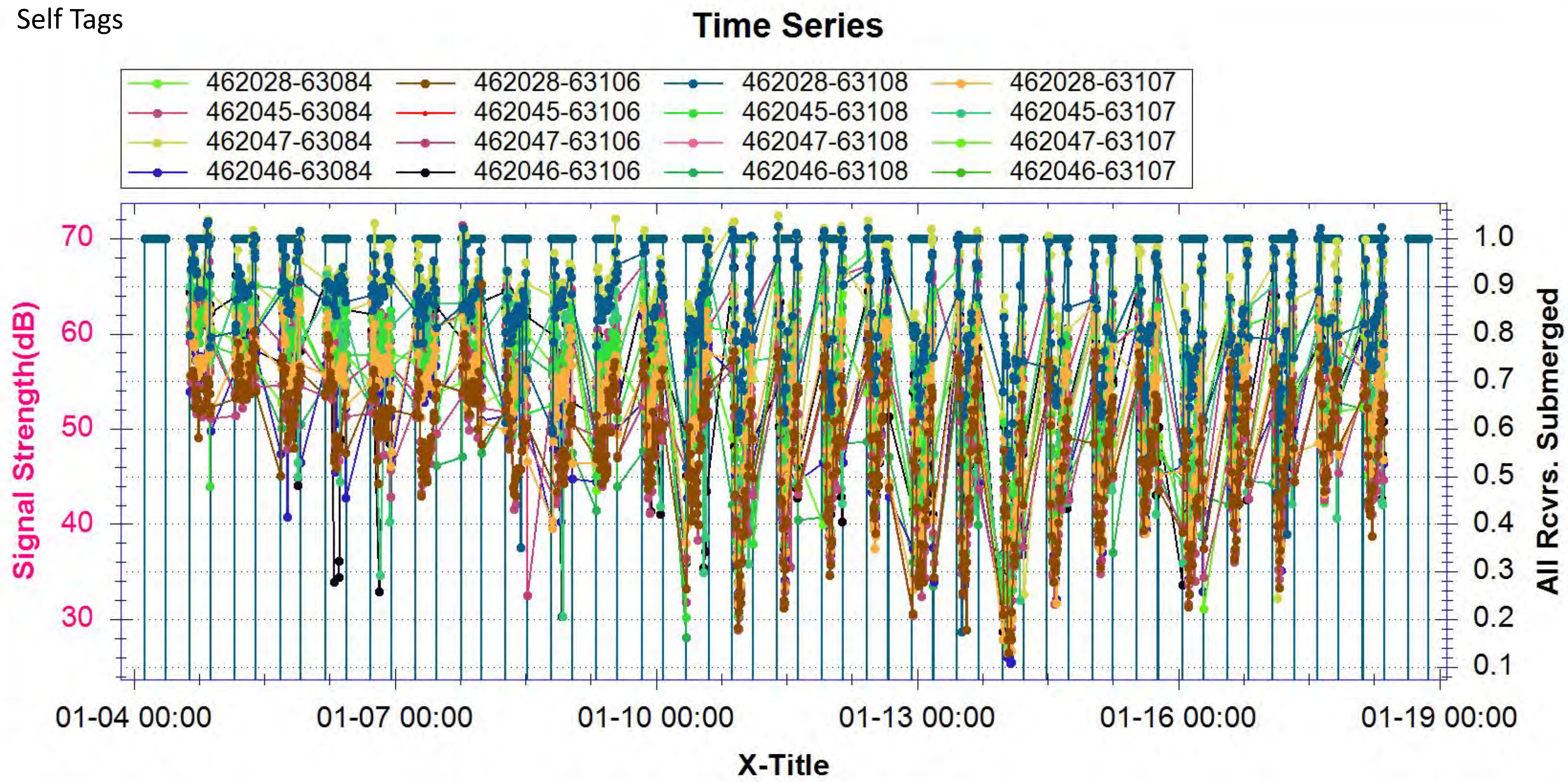
Rcvr. Detection Performance (Reflections)



180 kHz

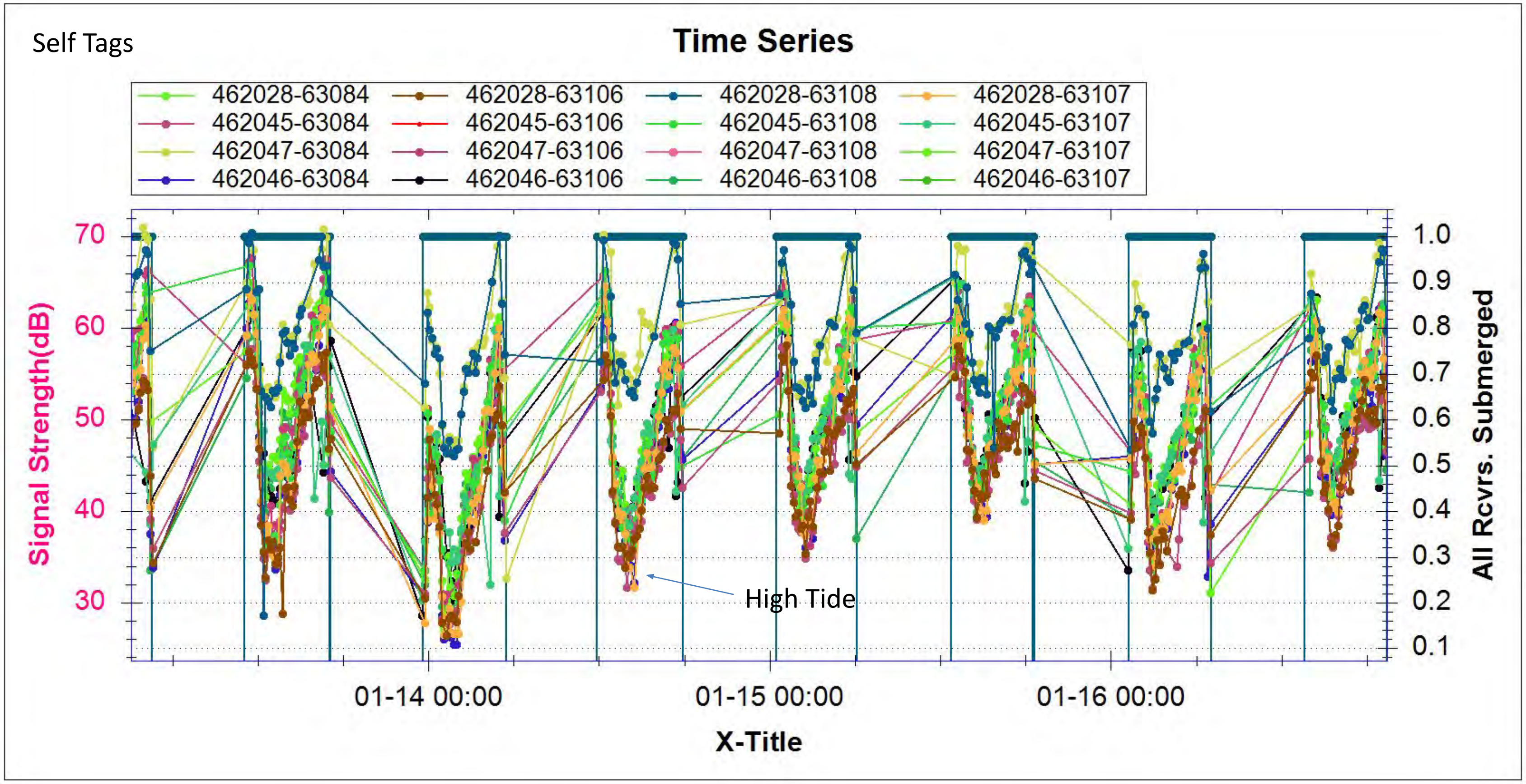
Rcvr. Detection Performance (Signal Strength)

Self Tags



180 kHz

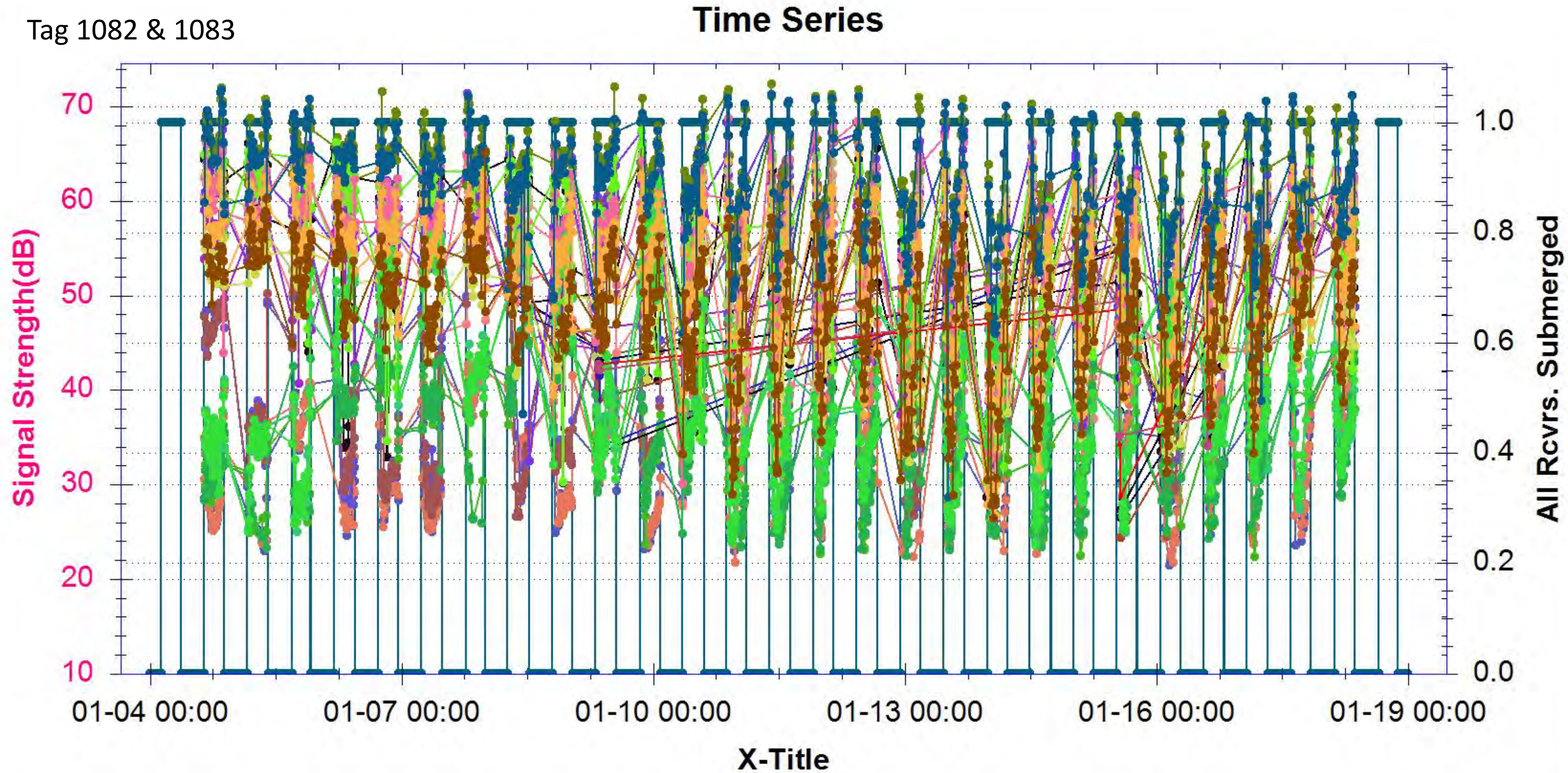
Rcvr. Detection Performance (Signal Strength)



180 kHz

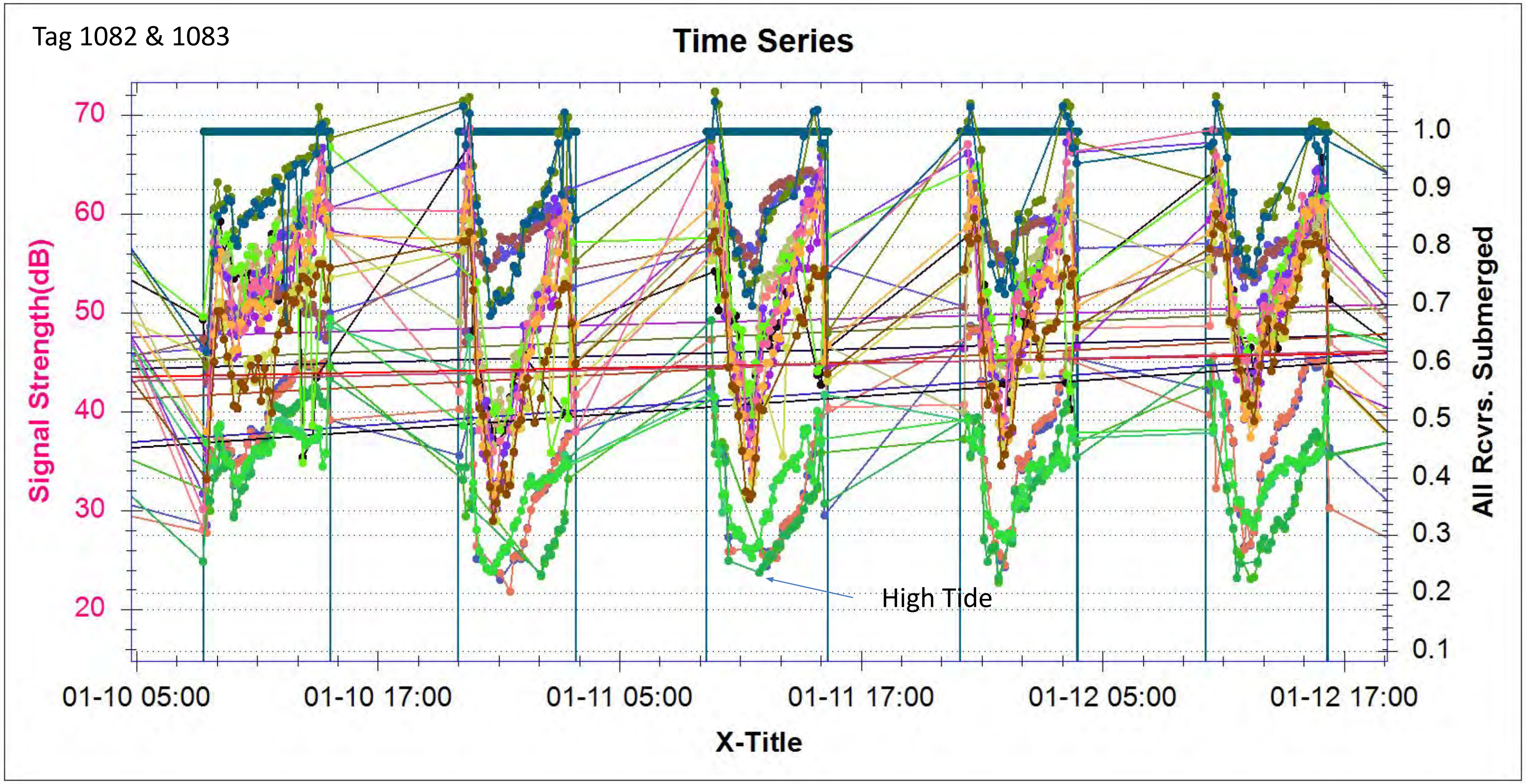
Rcvr. Detection Performance (Signal Strength)

Tag 1082 & 1083



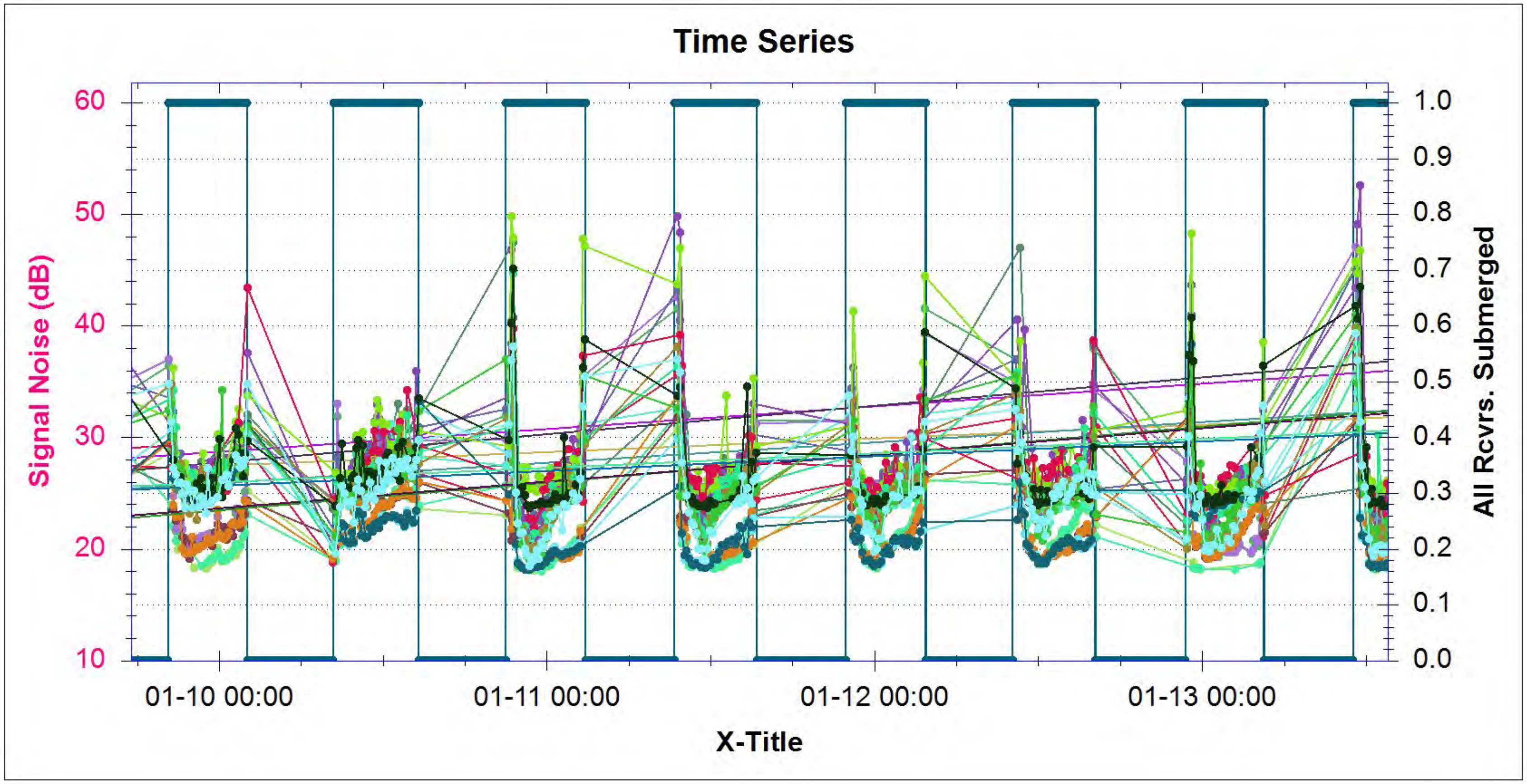
180 kHz

Rcvr. Detection Performance (Signal Strength)

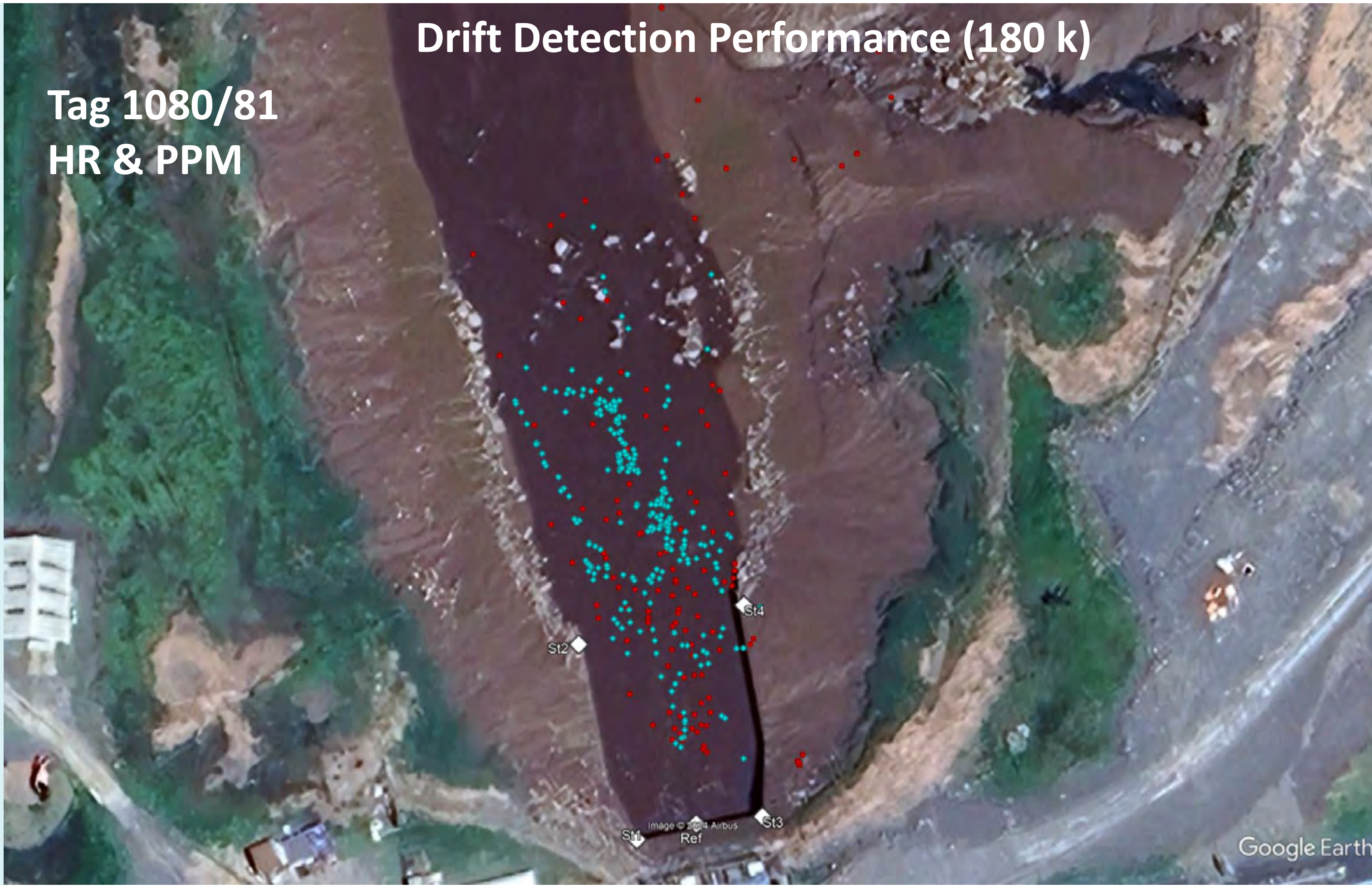


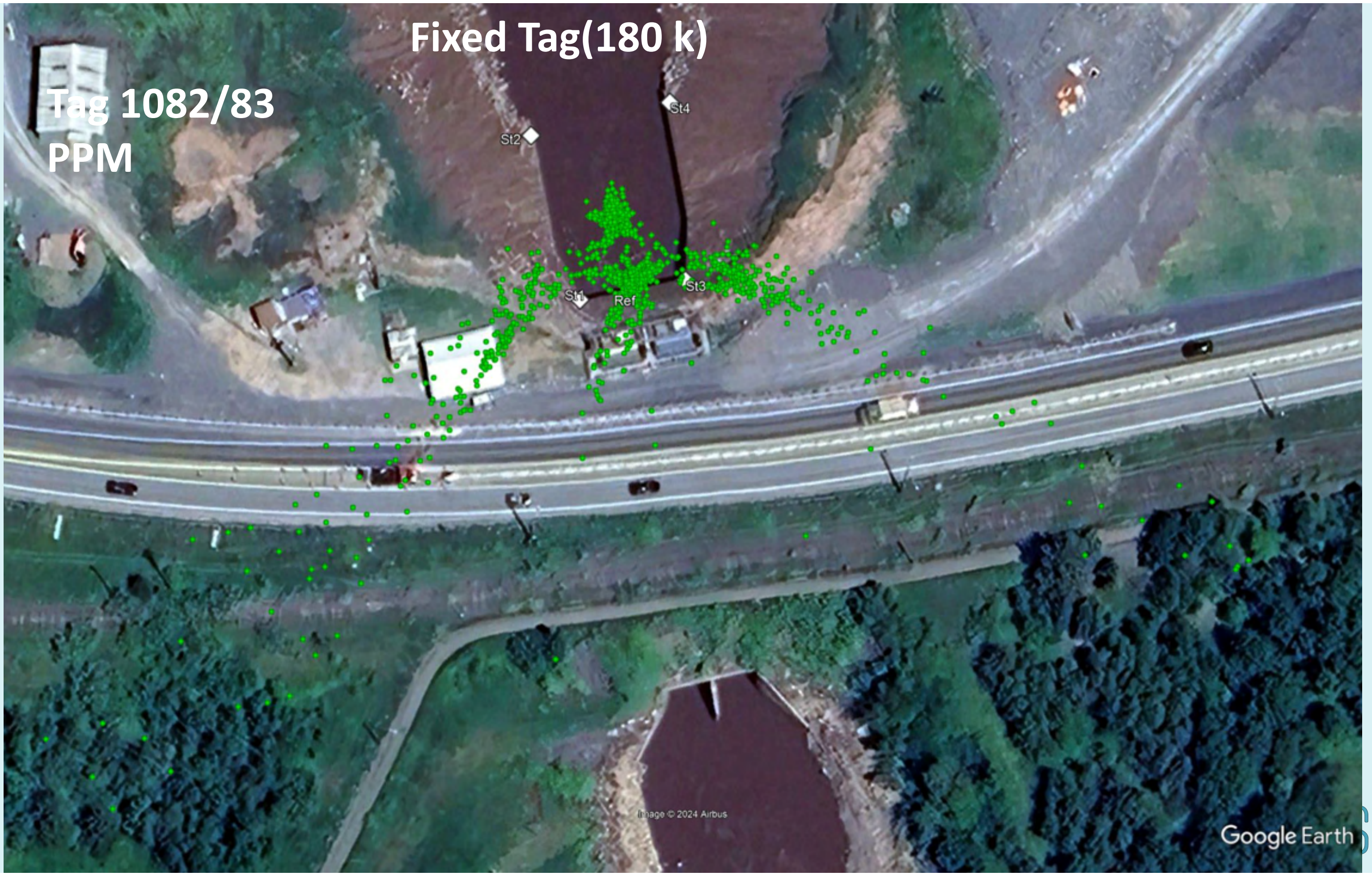
180 kHz

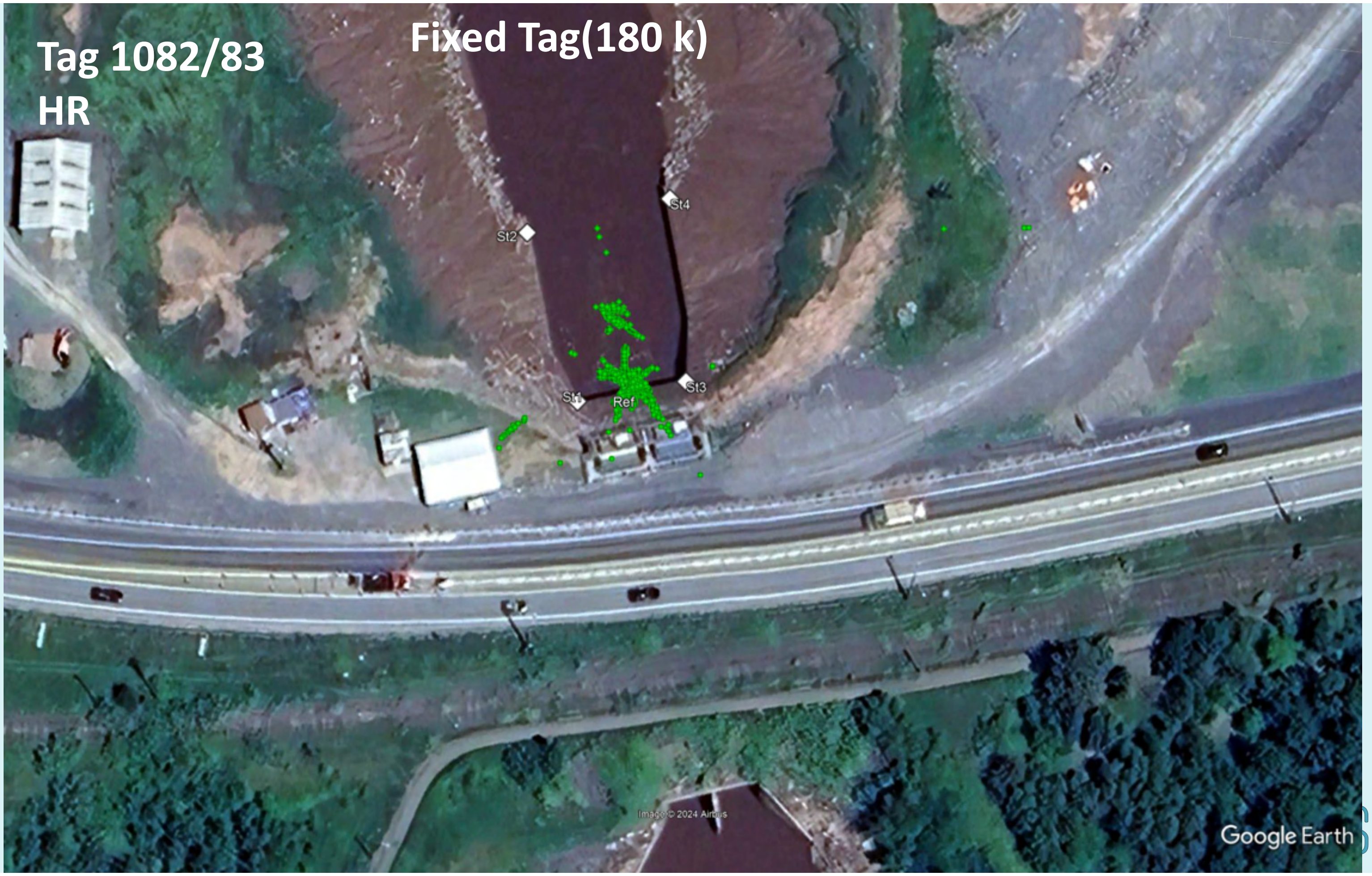
Rcvr. Detection Performance (Signal Noise)



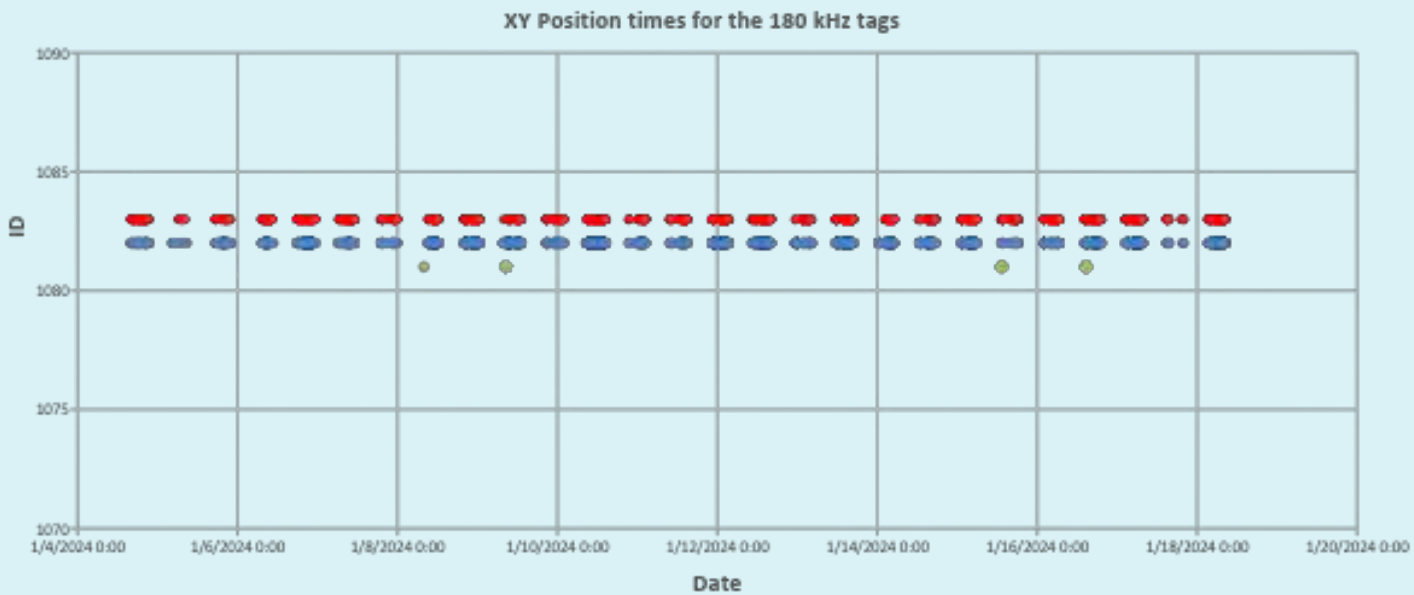
Drift Detection Performance (180 k)



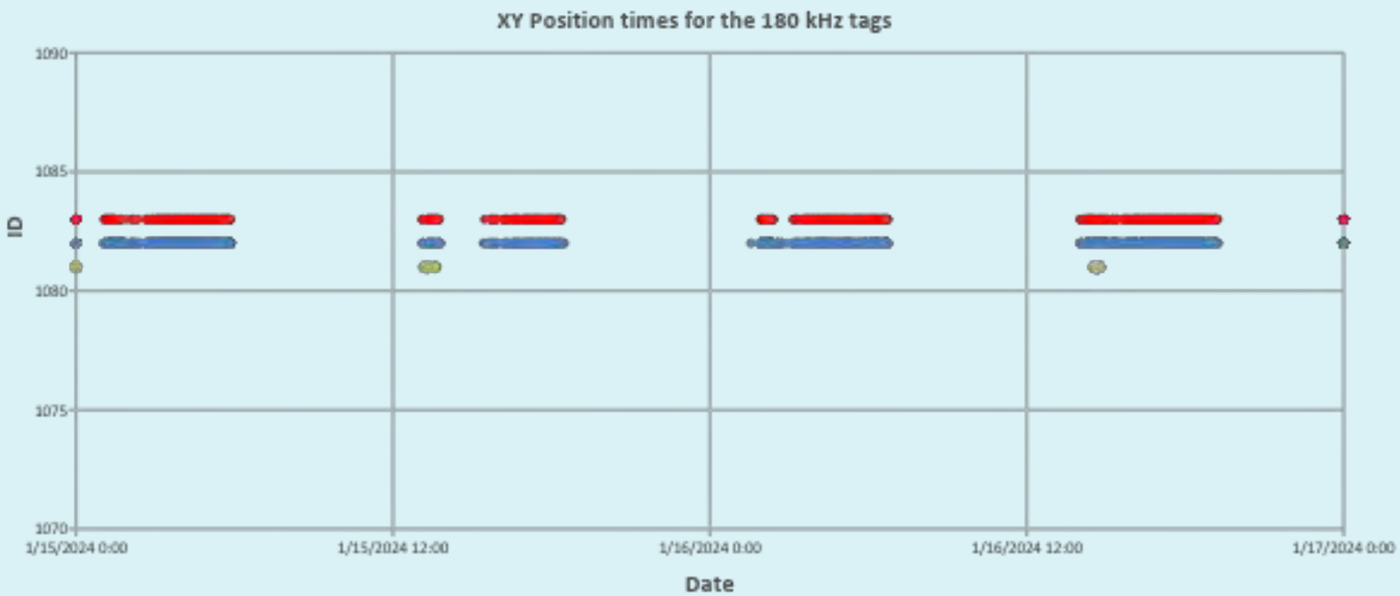

Fixed Tag(180 k)
Tag 1082/83
PPM
St4
St2
St1
Ref
St3
Image © 2024 Airbus
Google Earth


Tag 1082/83
HR
Fixed Tag(180 k)
St2
St4
St1
Ref
St3
Image © 2024 Airbus
Google Earth

Time of XY Position Data (180 k)



Time of XY Position Data (180 k)
(Zoomed in)



INNOVASEA

Summary

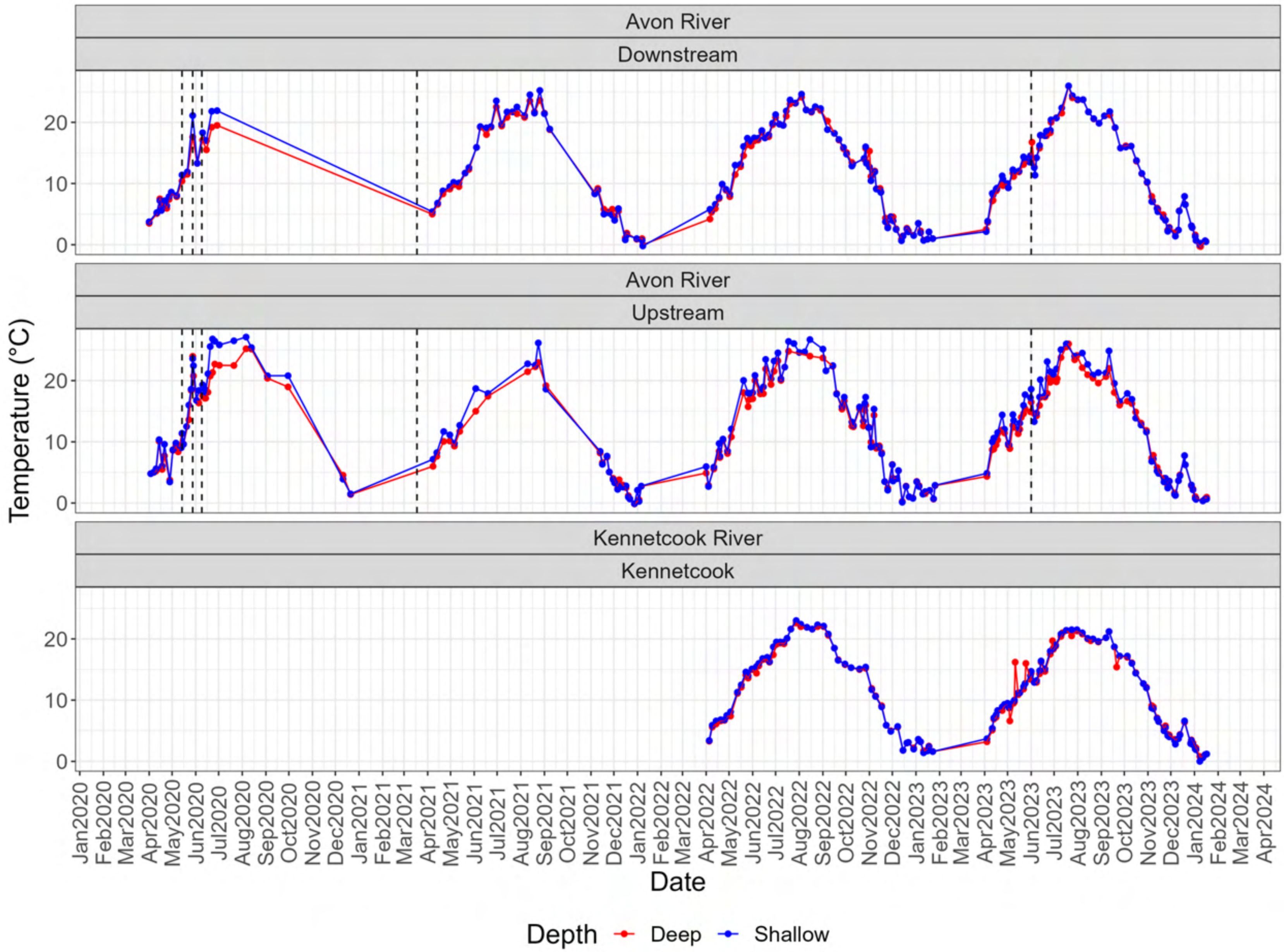
- GPS track data was intermittent and not on a fixed interval. I could not correlate the calculated XY position of a tag with a GPS track position.
- Detection Performance was generally qute good when rcvrs. were submerged
- Positioning Data was not filtered. After filtering the data should clean up a bit
- High Acoustic Noise as seen on HR2 Rcvrs. impacted detection performance during periods of high flow
- 307 kHz provided better rcvr. to rcvr. detection performance.
- 180 kHz detection performance & positioning likely suffered as a result of acoustic reflections. Lowering Self tag power should help.
- 307 kHz might work well if tags are programmed with a modulated signal and/or with a longer ping duration (5 ms)
- Absence/presence could provide an indication of residence times

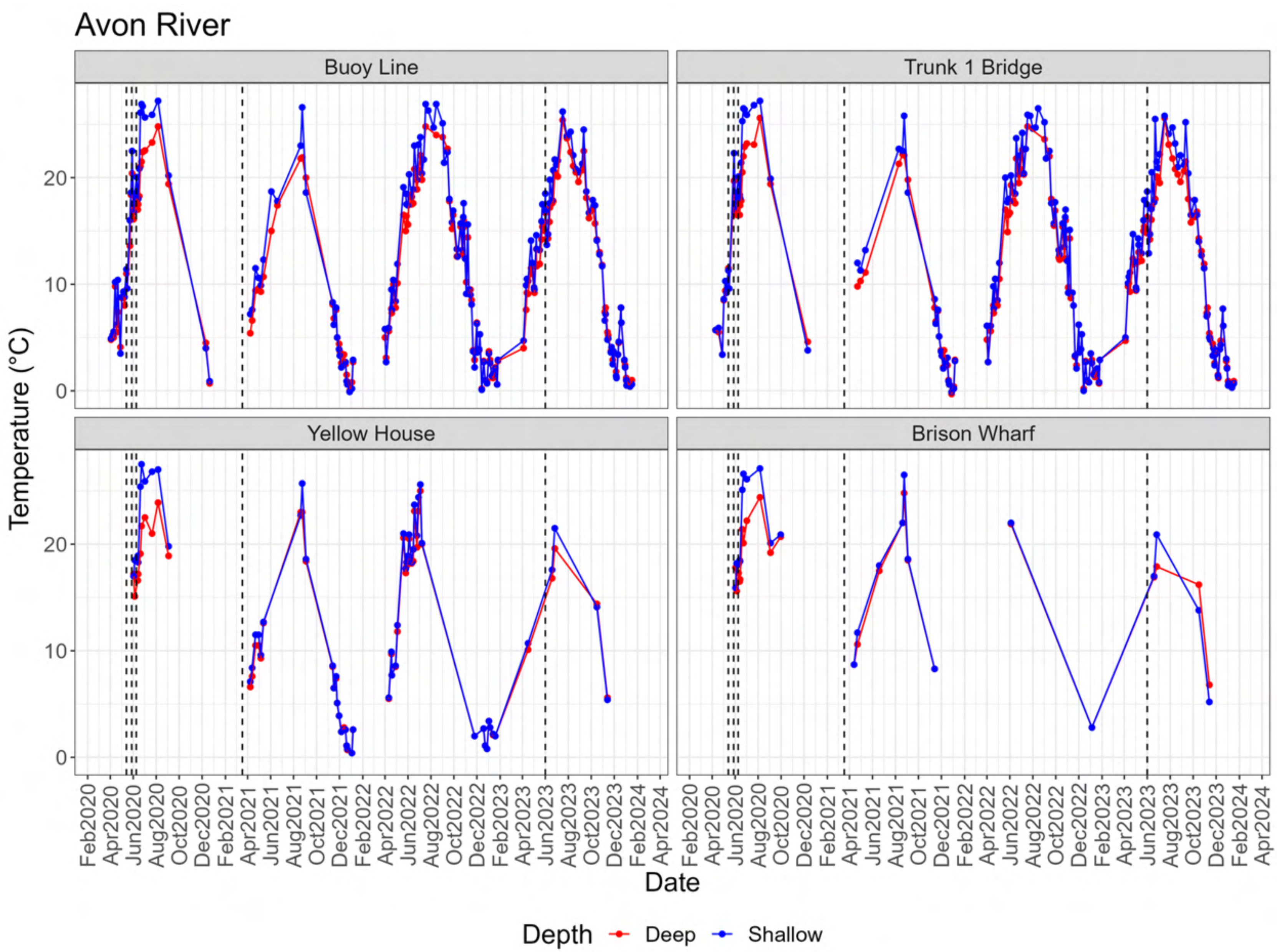
INNOVASEA

Appendix H - Water Quality

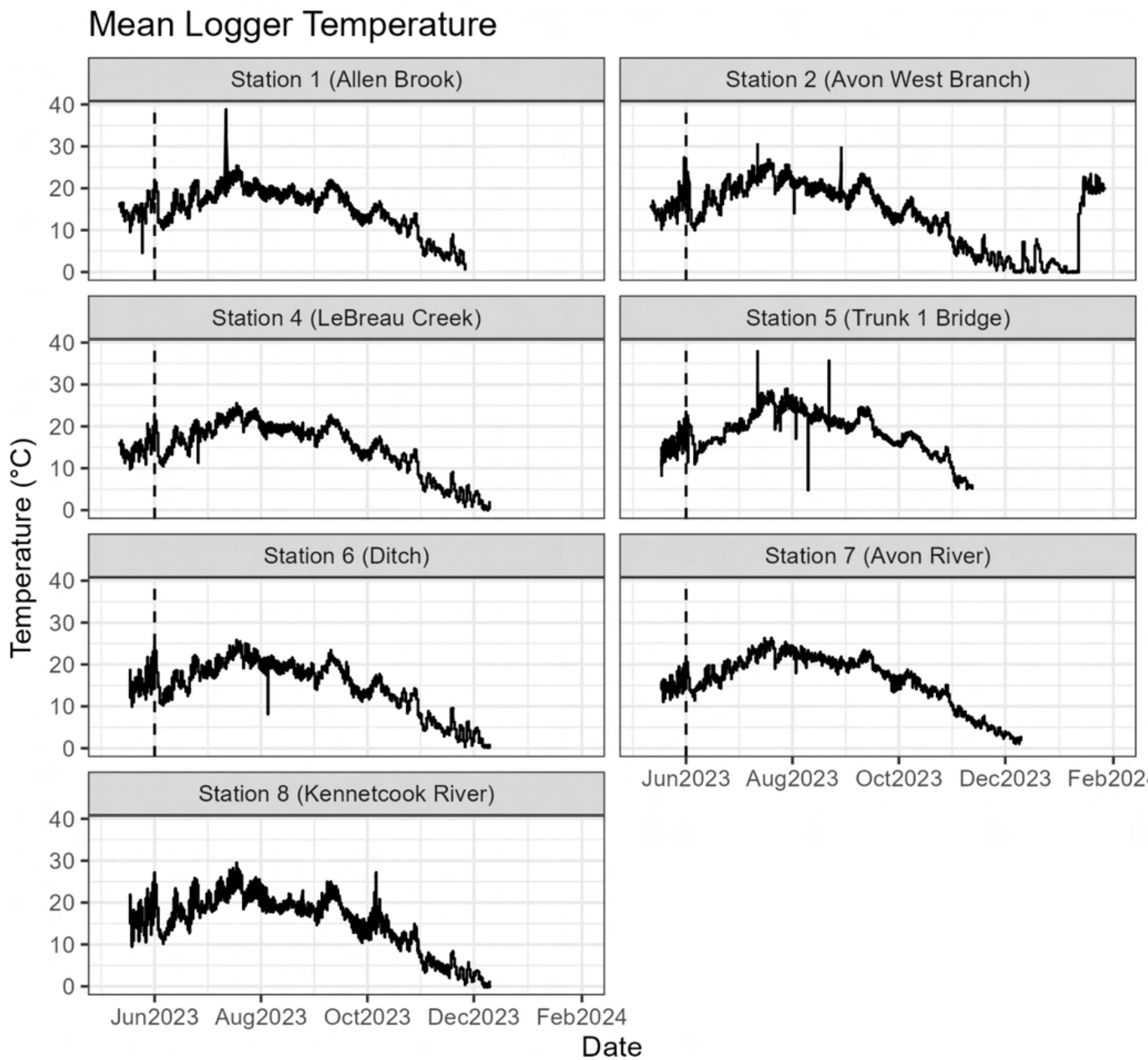
Vertical dashed lines represent notable events for gate operations:

-May 6, 2019 (reservoir level dropped for maintenance on one tide)
-May 21, 2019 (reservoir dropped and began providing fish passage for about 1 week)
-May 14, 2020 (first Ministerial Order issued)
-May 28, 2020 (reservoir established)
-June 9, 2020 (reservoir level raised, some saltwater entry occurred until Sept 2020)
-March 18, 2021 (second Ministerial Order issued)
-June 1, 2023 (provincial State of Emergency issued, reservoir established)

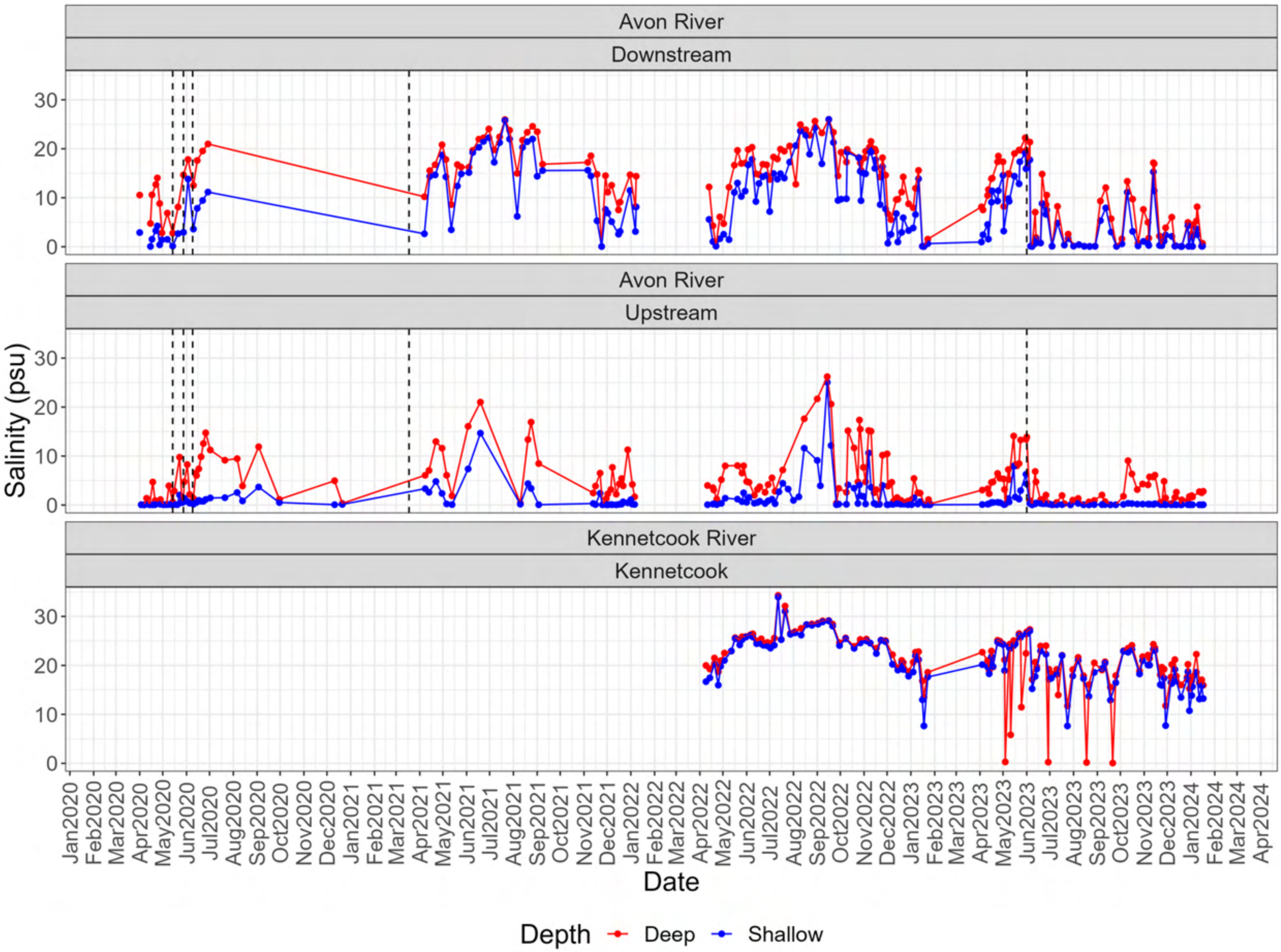

Avon River
Downstream
Avon River
Upstream
Kennetcook River
Kennetcook
Temperature (°C)
0
10
20
Jan2020
Feb2020
Mar2020
Apr2020
May2020
Jun2020
Jul2020
Aug2020
Sep2020
Oct2020
Nov2020
Dec2020
Jan2021
Feb2021
Mar2021
Apr2021
May2021
Jun2021
Jul2021
Aug2021
Sep2021
Oct2021
Nov2021
Dec2021
Jan2022
Feb2022
Mar2022
Apr2022
May2022
Jun2022
Jul2022
Aug2022
Sep2022
Oct2022
Nov2022
Dec2022
Jan2023
Feb2023
Mar2023
Apr2023
May2023
Jun2023
Jul2023
Aug2023
Sep2023
Oct2023
Nov2023
Dec2023
Jan2024
Feb2024
Mar2024
Apr2024
Date
Depth
Deep
Shallow

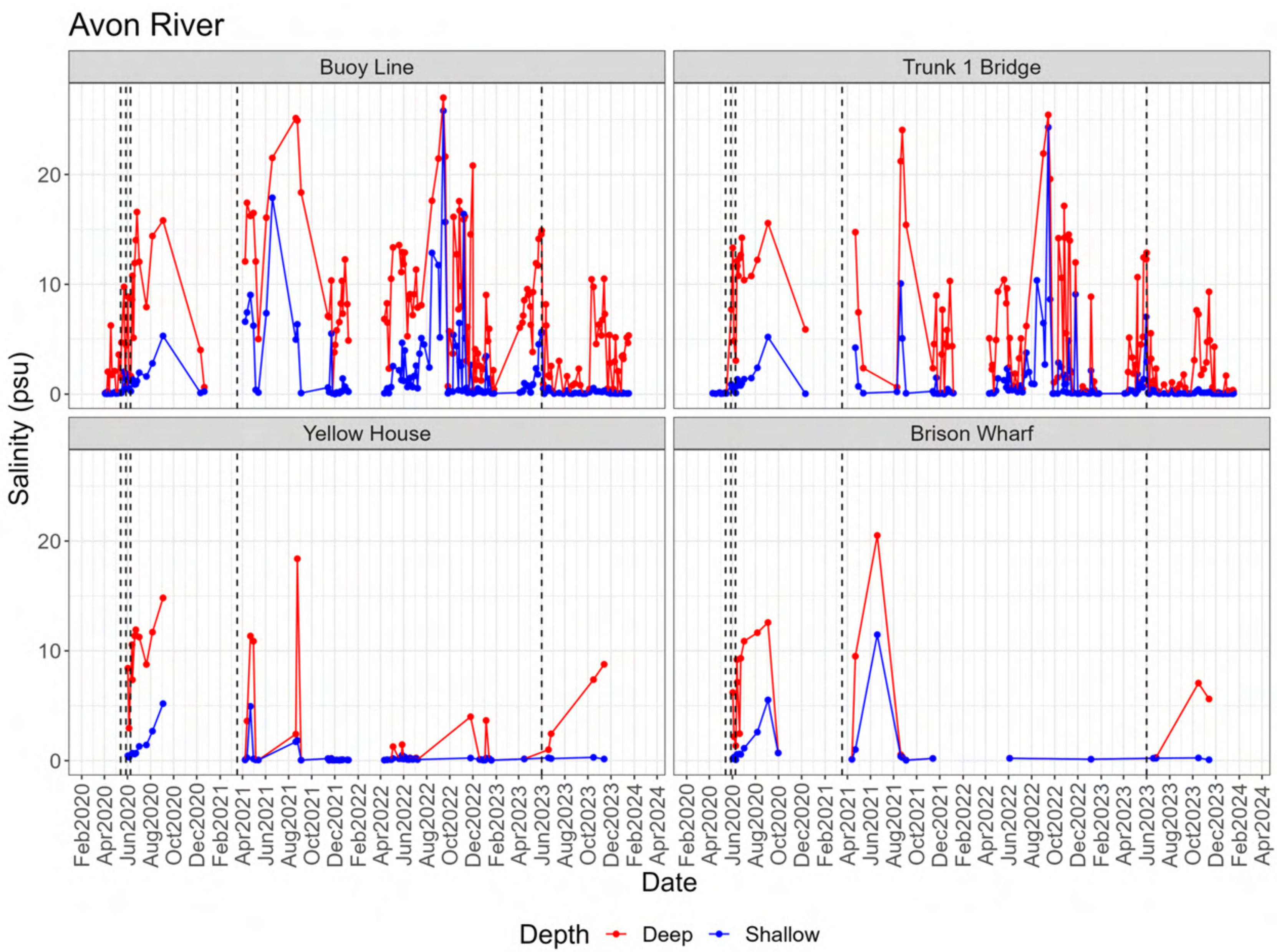


Avon River
Buoy Line
Trunk 1 Bridge
Yellow House
Brison Wharf
Temperature (°C)
0
10
20
Feb2020
Apr2020
Jun2020
Aug2020
Oct2020
Dec2020
Feb2021
Apr2021
Jun2021
Aug2021
Oct2021
Dec2021
Feb2022
Apr2022
Jun2022
Aug2022
Oct2022
Dec2022
Feb2023
Apr2023
Jun2023
Aug2023
Oct2023
Dec2023
Feb2024
Apr2024
Date
Depth
Deep
Shallow



Mean Logger Temperature
Station 1 (Allen Brook)
Station 2 (Avon West Branch)
Station 4 (LeBreau Creek)
Station 5 (Trunk 1 Bridge)
Station 6 (Ditch)
Station 7 (Avon River)
Station 8 (Kennetcook River)
Temperature (°C)
0
10
20
30
40
Jun2023
Aug2023
Oct2023
Dec2023
Feb2024
Date


Avon River
Downstream
Avon River
Upstream
Kennetcook River
Kennetcook
Salinity (psu)
0
10
20
30
Jan2020
Feb2020
Mar2020
Apr2020
May2020
Jun2020
Jul2020
Aug2020
Sep2020
Oct2020
Nov2020
Dec2020
Jan2021
Feb2021
Mar2021
Apr2021
May2021
Jun2021
Jul2021
Aug2021
Sep2021
Oct2021
Nov2021
Dec2021
Jan2022
Feb2022
Mar2022
Apr2022
May2022
Jun2022
Jul2022
Aug2022
Sep2022
Oct2022
Nov2022
Dec2022
Jan2023
Feb2023
Mar2023
Apr2023
May2023
Jun2023
Jul2023
Aug2023
Sep2023
Oct2023
Nov2023
Dec2023
Jan2024
Feb2024
Mar2024
Apr2024
Date
Depth
Deep
Shallow



Avon River
Buoy Line
Trunk 1 Bridge
Yellow House
Brison Wharf
Salinity (psu)
0
10
20
Feb2020
Apr2020
Jun2020
Aug2020
Oct2020
Dec2020
Feb2021
Apr2021
Jun2021
Aug2021
Oct2021
Dec2021
Feb2022
Apr2022
Jun2022
Aug2022
Oct2022
Dec2022
Feb2023
Apr2023
Jun2023
Aug2023
Oct2023
Dec2023
Feb2024
Apr2024
Date
Depth
Deep
Shallow

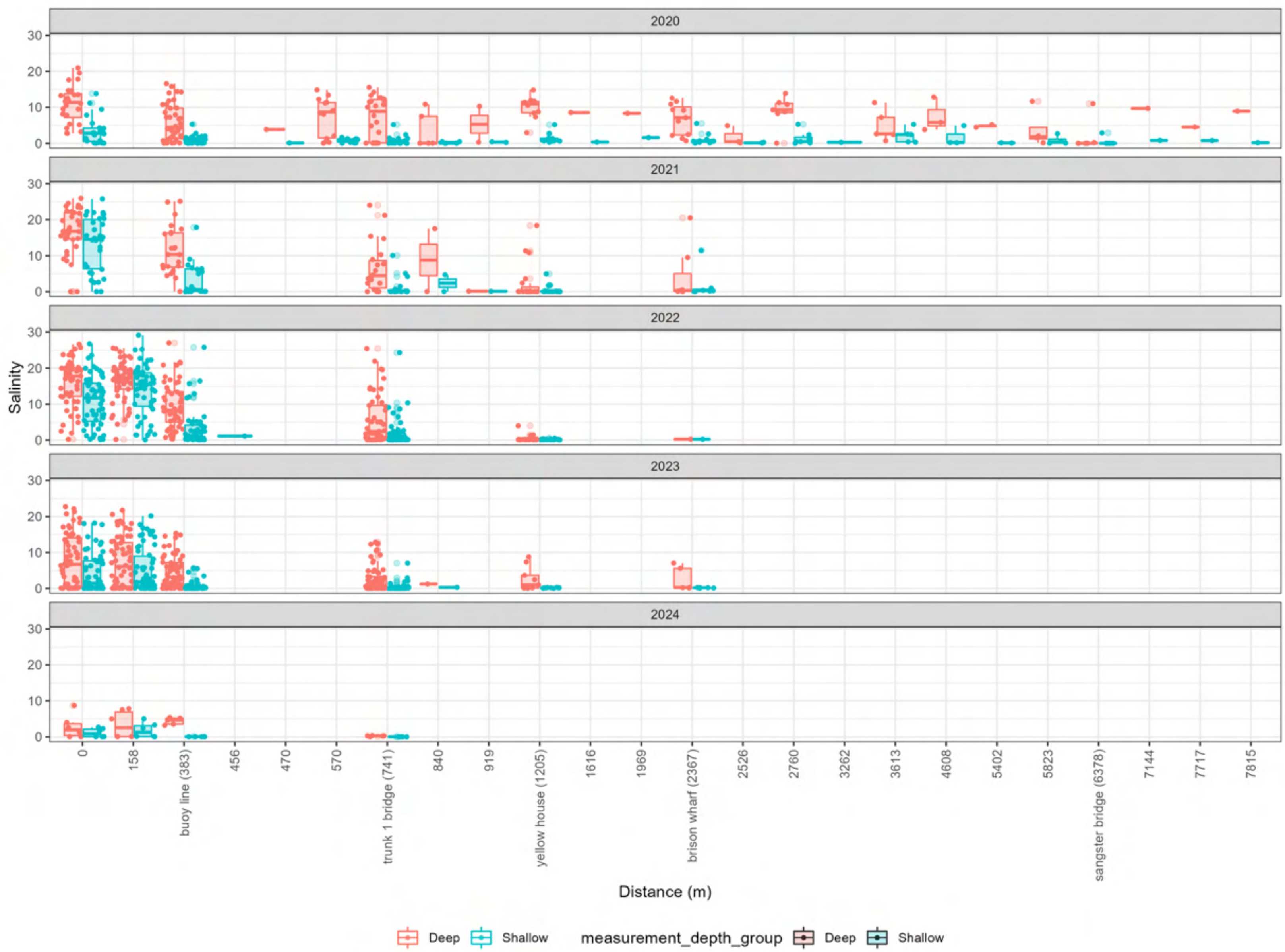
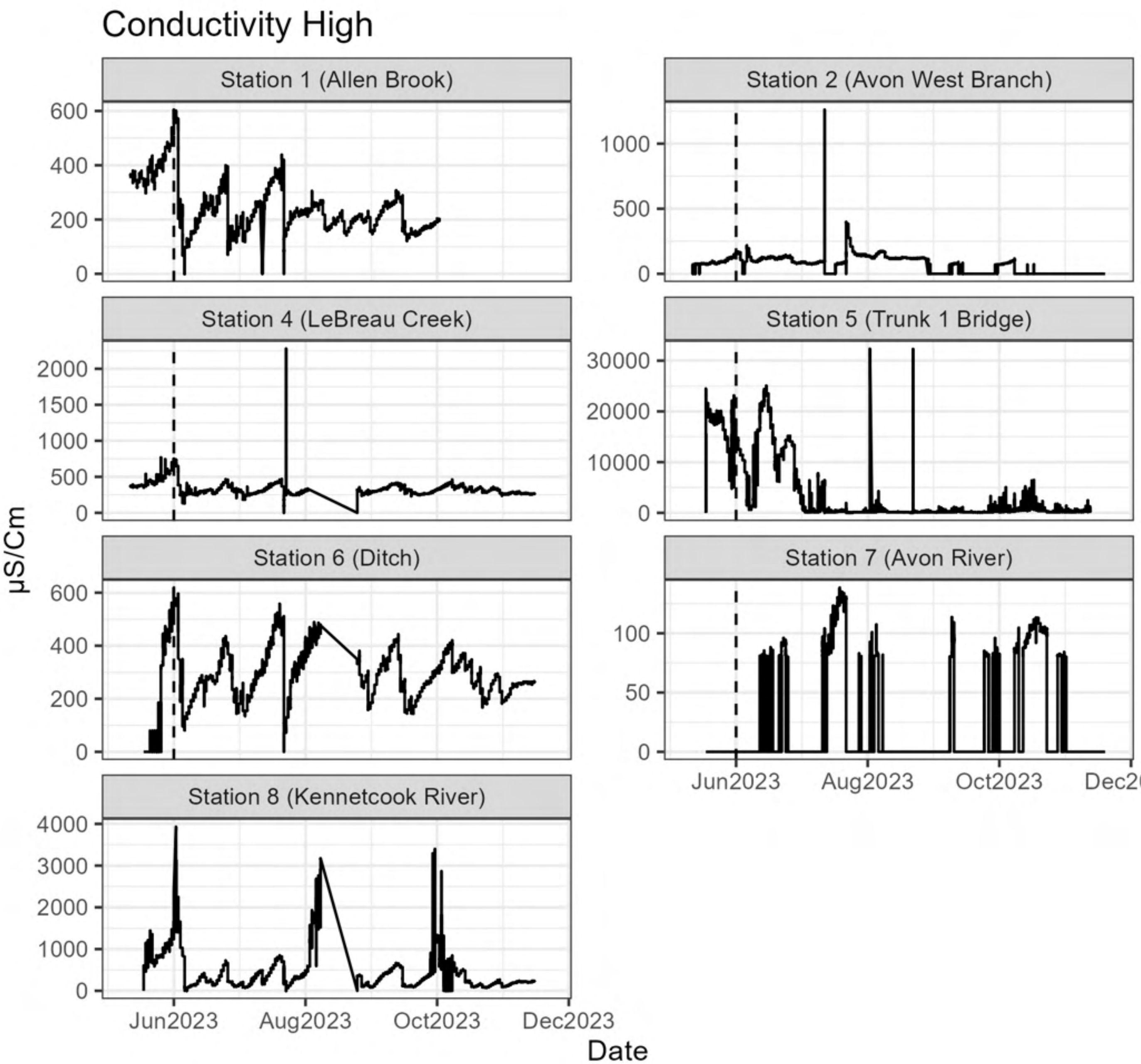
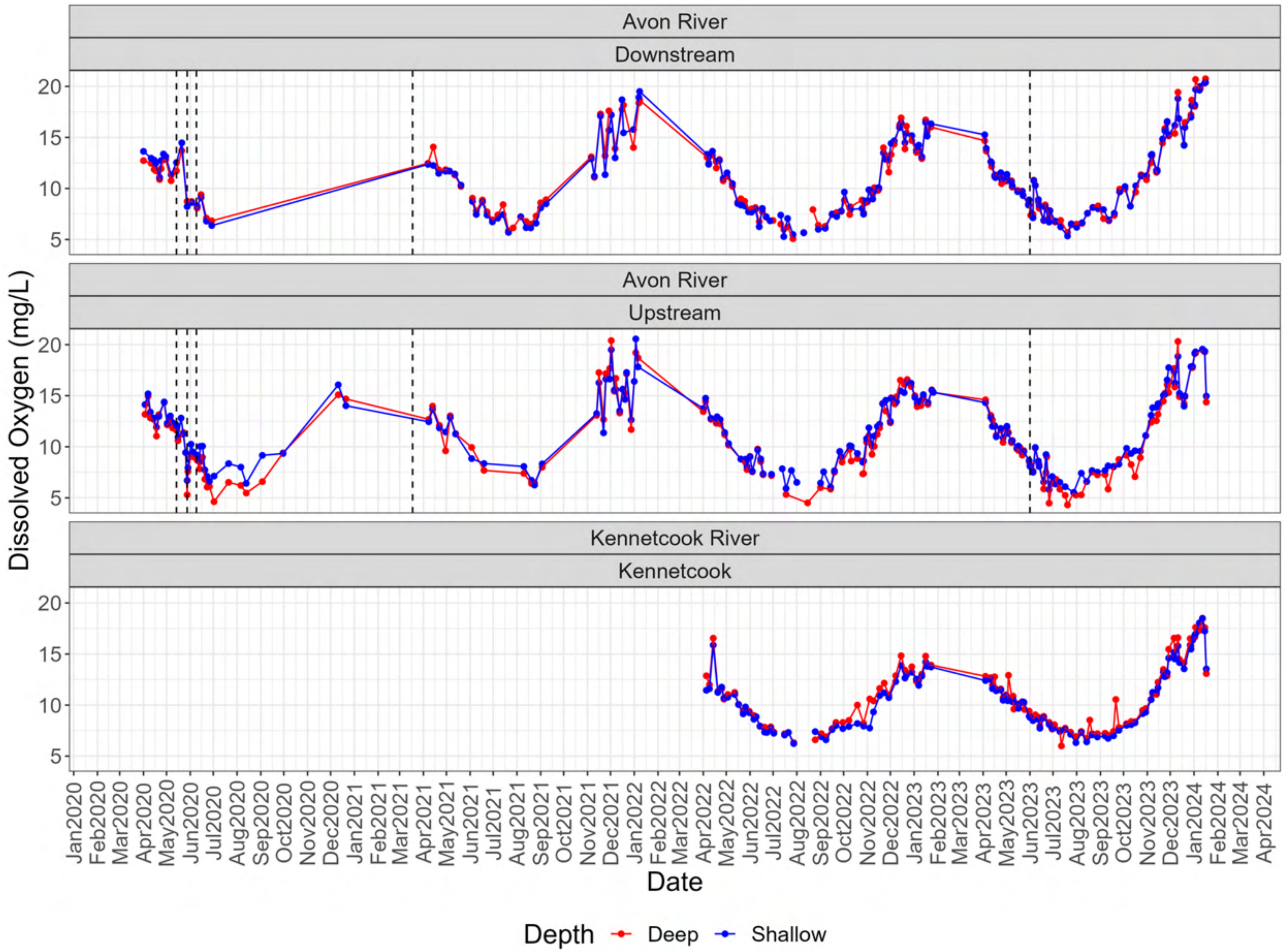
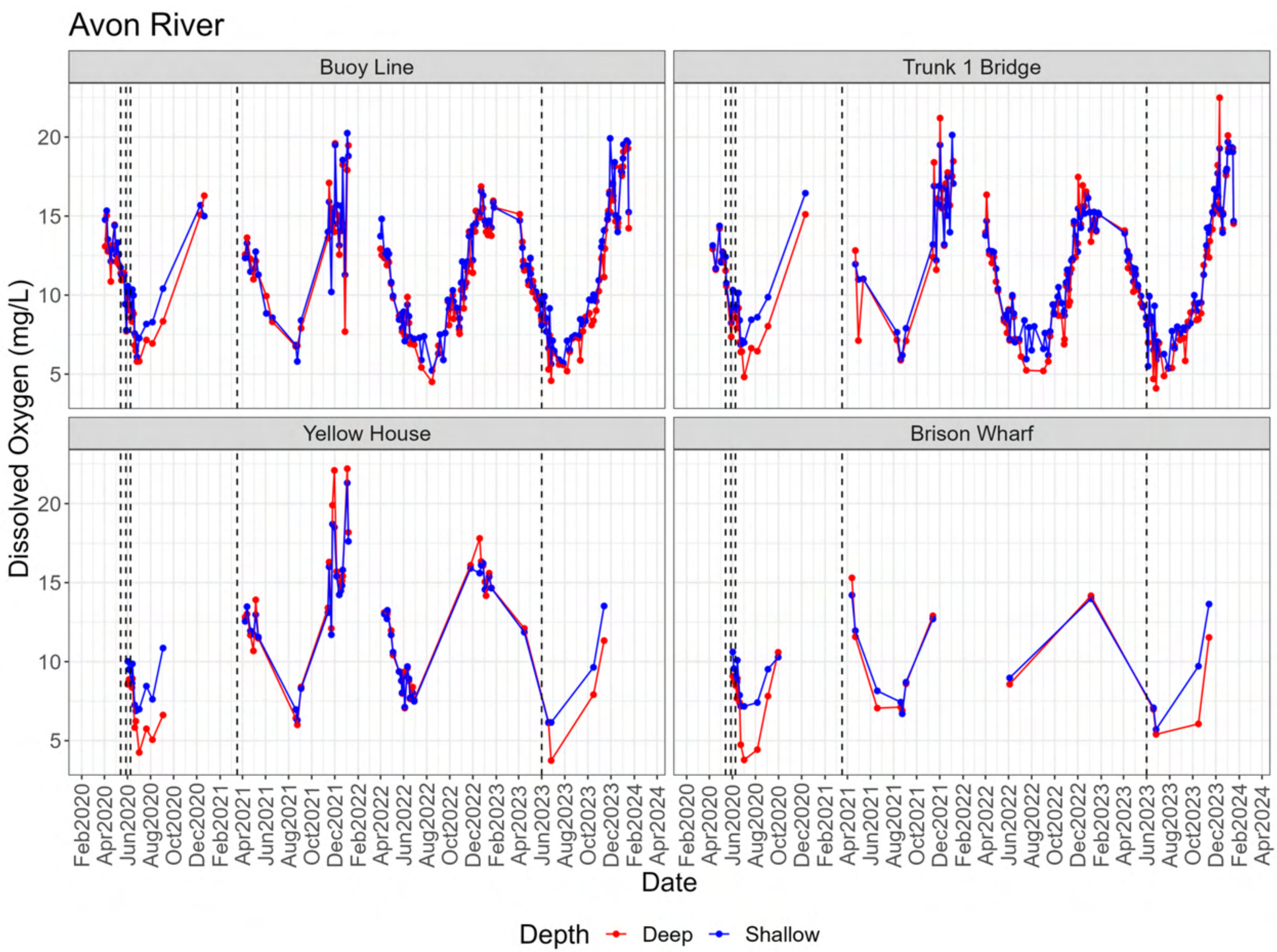


Figure 32 Salinity by distance upstream of causeway.

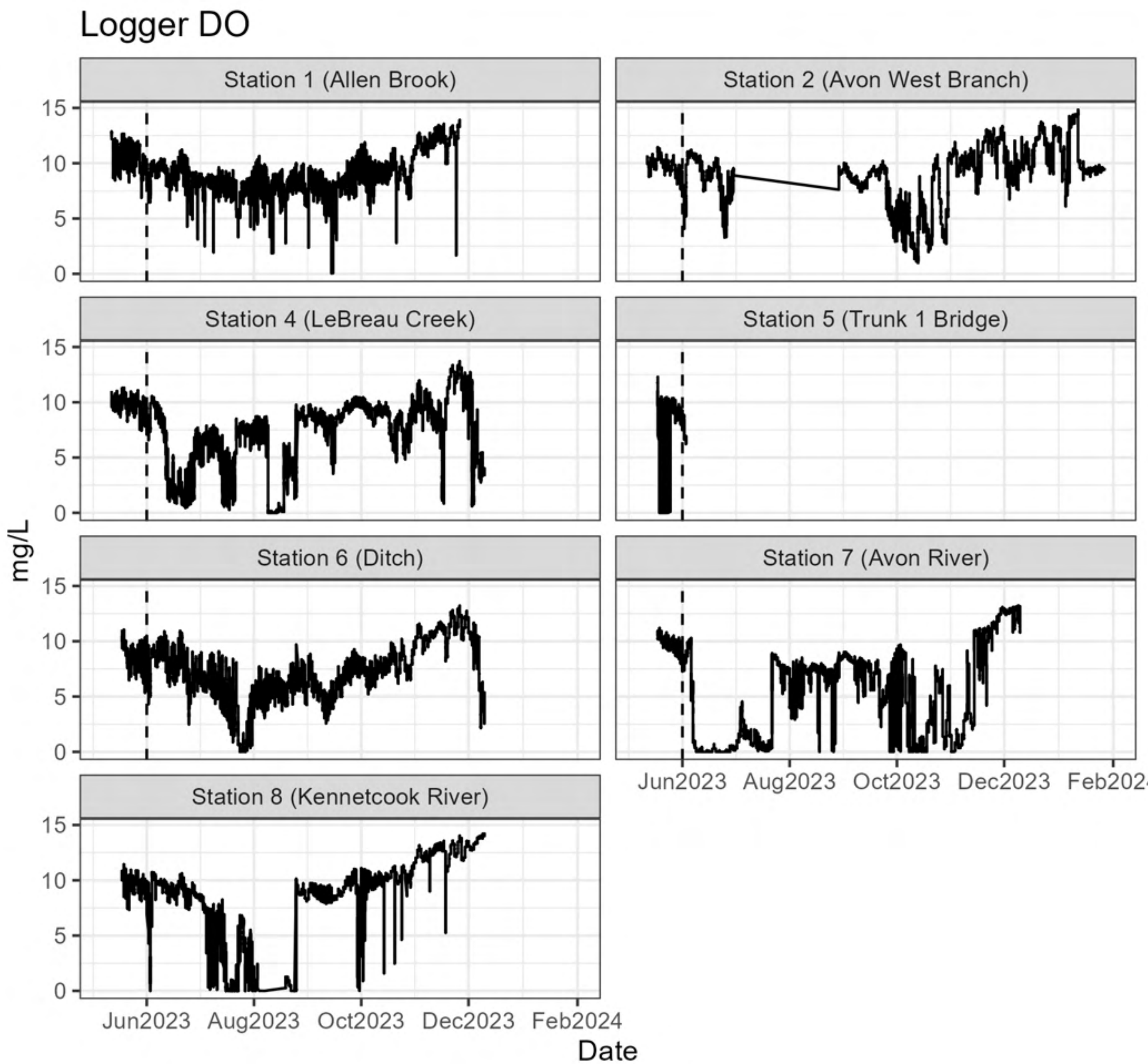

Conductivity High
Station 1 (Allen Brook)
Station 2 (Avon West Branch)
Station 4 (LeBreau Creek)
Station 5 (Trunk 1 Bridge)
Station 6 (Ditch)
Station 7 (Avon River)
Station 8 (Kennetcook River)
µS/Cm
Date
Jun2023
Aug2023
Oct2023
Dec2023

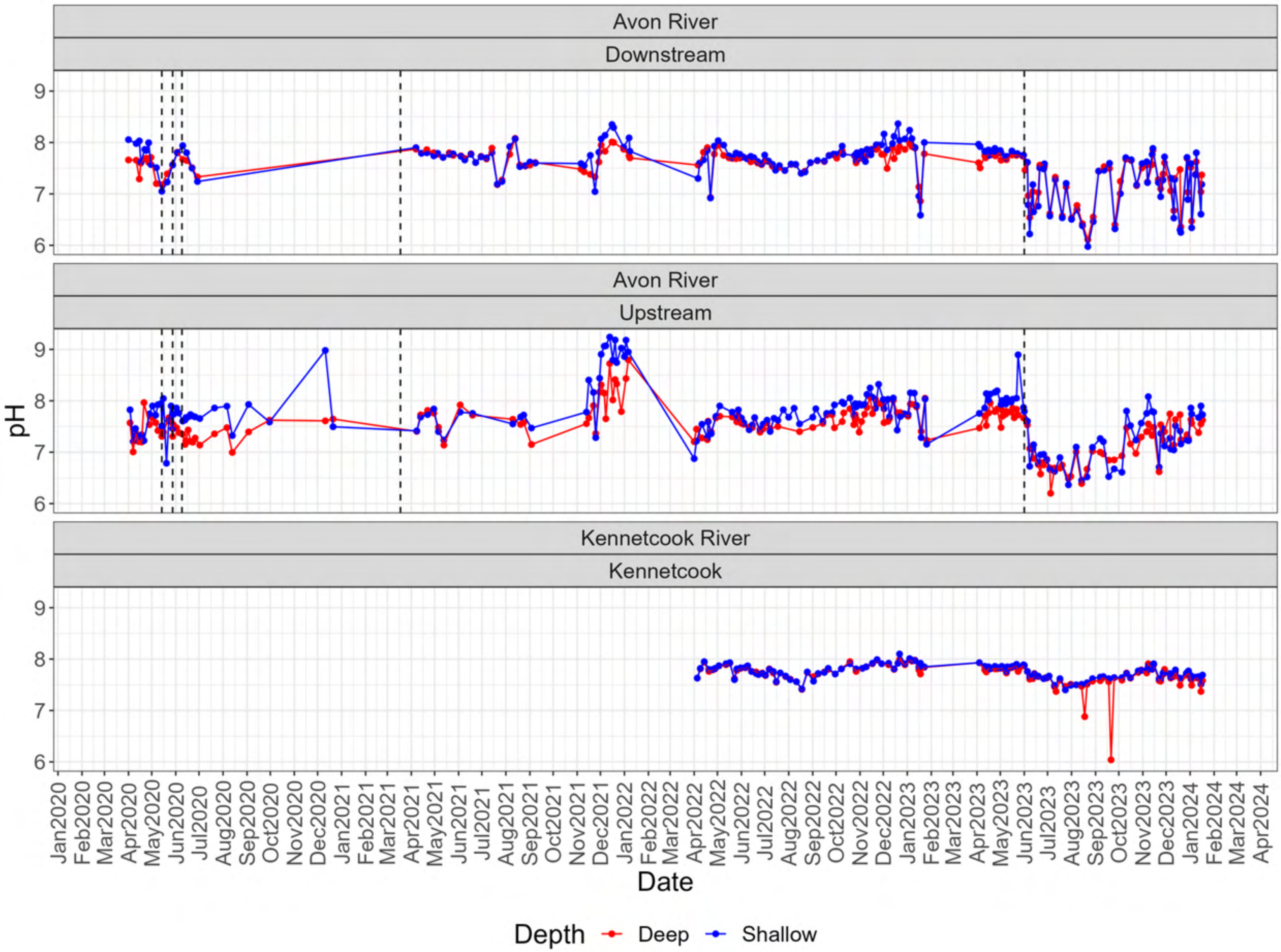


Avon River
Downstream
Avon River
Upstream
Kennetcook River
Kennetcook
Dissolved Oxygen (mg/L)
20
15
10
5
Jan2020
Feb2020
Mar2020
Apr2020
May2020
Jun2020
Jul2020
Aug2020
Sep2020
Oct2020
Nov2020
Dec2020
Jan2021
Feb2021
Mar2021
Apr2021
May2021
Jun2021
Jul2021
Aug2021
Sep2021
Oct2021
Nov2021
Dec2021
Jan2022
Feb2022
Mar2022
Apr2022
May2022
Jun2022
Jul2022
Aug2022
Sep2022
Oct2022
Nov2022
Dec2022
Jan2023
Feb2023
Mar2023
Apr2023
May2023
Jun2023
Jul2023
Aug2023
Sep2023
Oct2023
Nov2023
Dec2023
Jan2024
Feb2024
Mar2024
Apr2024
Date
Depth
Deep
Shallow



Avon River
Buoy Line
Trunk 1 Bridge
Yellow House
Brison Wharf
Dissolved Oxygen (mg/L)
20
15
10
5
Feb2020
Apr2020
Jun2020
Aug2020
Oct2020
Dec2020
Feb2021
Apr2021
Jun2021
Aug2021
Oct2021
Dec2021
Feb2022
Apr2022
Jun2022
Aug2022
Oct2022
Dec2022
Feb2023
Apr2023
Jun2023
Aug2023
Oct2023
Dec2023
Feb2024
Apr2024
Date
Depth
Deep
Shallow


Logger DO
Station 1 (Allen Brook)
Station 2 (Avon West Branch)
Station 4 (LeBreau Creek)
Station 5 (Trunk 1 Bridge)
Station 6 (Ditch)
Station 7 (Avon River)
Station 8 (Kennetcook River)
mg/L
15
10
5
0
Jun2023
Aug2023
Oct2023
Dec2023
Feb2024
Date


Avon River
Downstream
Avon River
Upstream
Kennetcook River
Kennetcook
pH
9
8
7
6
Jan2020
Feb2020
Mar2020
Apr2020
May2020
Jun2020
Jul2020
Aug2020
Sep2020
Oct2020
Nov2020
Dec2020
Jan2021
Feb2021
Mar2021
Apr2021
May2021
Jun2021
Jul2021
Aug2021
Sep2021
Oct2021
Nov2021
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Apr2022
May2022
Jun2022
Jul2022
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Jan2023
Feb2023
Mar2023
Apr2023
May2023
Jun2023
Jul2023
Aug2023
Sep2023
Oct2023
Nov2023
Dec2023
Jan2024
Feb2024
Mar2024
Apr2024
Date
Depth
Deep
Shallow

Avon River
Buoy Line
Trunk 1 Bridge
Yellow House
Brison Wharf
pH
10
9
8
7
Feb2020
Apr2020
Jun2020
Aug2020
Oct2020
Dec2020
Feb2021
Apr2021
Jun2021
Aug2021
Oct2021
Dec2021
Feb2022
Apr2022
Jun2022
Aug2022
Oct2022
Dec2022
Feb2023
Apr2023
Jun2023
Aug2023
Oct2023
Dec2023
Feb2024
Apr2024
Date
Depth
Deep
Shallow